# DIVER ASSESSMENT OF THE INSHORE SOUTHEASTERN LAKE MICHIGAN ENVIRONMENT NEAR THE D. C. COOK NUCLEAR PLANT, 1973-82

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# INTRODUCTION

This report is a summary and analysis of observations made by divers in southeastern Lake Michigan near the D. C. Cook Nuclear Plant, 1973-1982. This investigation was one component of a multi-disciplinary environmental impact study conducted by the Great Lakes Research Division, University of Michigan, for the Donald C. Cook Nuclear Plant from 1970 through 1982. Overall scope of work included: physical studies - hydrology, sediments, shore erosion, ice effects; chemical studies - standard water chemistry, nutrients, trace metals; and biological studies - psammo-littoral organisms, periphyton, algae, zooplankton, benthos, and fish. In addition, studies by other agencies included radiological work, weather and currents, thermal plume mapping, terrestrial flora and fauna, and other environmental, sociological, and economic assessments associated with plant site selection and pre-construction activities. In 1986, the various studies conducted by Great Lakes Research Division were integrated into an overview of the aquatic environment in the study area.

The purpose of the underwater assessment program was to gather data via direct observation or analysis of hand-collected samples. Information amassed through these efforts was used to collaborate or augment other studies at the Cook Plant and to provide a unique assessment of the aquatic environment, its ecology, and plant-induced effects.

The D. C. Cook Nuclear Plant is located in Berrien County on the shore of southeastern Lake Michigan near Bridgman, Michigan. The plant site was purchased in 1959 and pre-construction activities began in the 1960s. Construction of the two-unit, 2,200 megawatt plant began in the late 1960s. Placement of in-lake structures (intake and discharge pipes and structures,

and riprap field) was completed in late 1972. Unit 1 achieved "on-line" status during 1975, following a prior startup period in 1974. Unit 2 went on-line during 1977. Great Lakes Research Division studies began at the Cook Plant in 1970 and were divided into two general phases: preoperational and operational. Underwater studies were conducted during 1973-1982 and included 10 annual periods of observation from April through October during most years. In accordance with the plant construction schedule, the preoperational study period began in 1970 and extended through 1974 when Unit 1 went on-line. Therefore, the preoperational database for diving observations encompassed the 2-yr period from 1973 to 1974. Operational studies were conducted from 1975 through 1982, although full operational status was not attained until late in the study.

An important feature of Cook Plant structure and operation regarding its potential effects on the lake was the presence of in-lake structures and once-through circulation of water to cool the plant reactors. At peak operation, 6.1 million liters per minute (1.6 million gpm) of water are drawn through a system of three water intakes located 223 m (2,250 ft) offshore in 9 m of water, circulated once through the plant, and returned to the lake via two discharge structures located 109 m (1,100 ft) offshore in 6 m of water. Aquatic biota entrained in the cooling water are exposed to physical and thermal effects, as is the environment immediately surrounding the discharge area. Also, the presence of in-lake plant structures (intakes and riprap) creates a physical environment that is atypical of the surrounding area.

Nearshore surficial sediments in the study area are typically composed of coarse- to medium-sized grained sand (1.0-0.25-mm diameter) with fine- to very fine-sized sand (0.25-0.06-mm diameter) becoming predominant offshore (Davis

and McGeary 1965, Hawley and Judge 1969). A distinct change in sediment composition that occurs offshore at about 24 m is a function of depth and severity of nearshore physical processes (Seibel et al. 1974, Rossmann and Seibel 1977). An accumulation of 1-10 mm of fine particulate material consisting of sediment, periphyton, organic detritus, and diatom tests often covers the bottom (Dorr and Jude 1980a, b). Inshore surficial sediments are unstable, and topography can be attributed to nearshore physical processes including waves and currents. Typical manifestations in the study area are an inner and outer bar and a gentle slope of 1:100 or less beyond a depth of 4 m (Davis and McGeary 1965). Thus most areas of the bottom exhibit only little relief and provide minimal to no surficial shelter or protection for macroscopic biota, e.g., fish, crustaceans, and molluscs. In contrast, substrate surrounding the intake and discharge structures and sub-surface water circulation pipes consists of crushed limestone riprap (0.1-1.0 m in diameter). It was installed during plant construction to reduce scour by plant discharge water on in-lake, cooling-water structures. In its central area, the riprap bed is mounded 1-2 m above bottom, and the structures rise an additional 3 m above the riprap. Consequently, the surface profile in the water intake and discharge areas is considerably more rugose than the surrounding natural environment.

The focus of our underwater studies was to examine selected features of this man-made environment and to compare and contrast them with those of the surrounding area. Through these observations, a better understanding of the aquatic environment in the vicinity of the plant was achieved, as well as of the plant impact on that environment. Patterns of colonization of aquatic biota were also delineated.

Within the report, Cook plant data and findings are integrated with other underwater studies conducted in Lake Michigan. Changes in the ecology of the Cook Plant area related to the impact of the plant are also discussed.

The knowledge gained through the underwater assessment study has provided unique insight into the inshore southeastern Lake Michigan environment. This insight augments that obtained from other components of the Cook Plant environmental study. Our results should help guide future similar studies, as well as add to the understanding of physical and biological processes in the Great Lakes and elsewhere.

# METHODS

The underwater assessment study at the Cook Plant is unique to the Great Lakes in two respects: its duration, which encompassed 10 separate field seasons, and its design. Diving began in 1973 and continued through 1982. During this period, 281 (221 day, 60 night) dives were performed in the study area (Table 1), and more than 161 h of underwater time were amassed. The area was examined by divers each month, April-October, for 8-10 seasons.

The second unique aspect of this study was the extent to which observational techniques, effort, and sampling were standardized. During 1973-1974, diving and underwater assessment techniques were developed for the study area and were incorporated into the Cook Plant environmental monitoring scheme for plant operation as required by the Nuclear Regulatory Commission and the Michigan Department of Natural Resources. These environmental technical specifications (U.S. Atomic Energy Commission 1975) were in effect from 1975 through completion of our field studies in 1982, and stringently defined baseline study objectives and sampling regimes for all sections of the Cook Plant environmental survey including underwater studies. Strict adherence to these specifications resulted in a sampling program that was both rigorous and relatively inflexible with regard to modifications. However, it had the advantage of generating a continuum of data that permitted identification and analysis of ecological patterns, changes, and plant impacts on the environment over a period of years.

Environmental technical specifications stipulated that visual observations would be conducted at least once per month, April through October, at five specified locations, including two dives (one day, one night) in the area of the intake structures, one day dive in the area of the

Table 1. Summary of day (D) and night (N) dives performed during 1973-1982 in southeastern Lake Michigan in the vicinity of the D. C. Cook Nuclear Plant near Bridgman, Michigan. Diving was not conducted during January, November, and December.

| Month | 1973 | | 1974 | | 1975 | | 1976 | | 1977 | | 1978 | | 1979 | | 1980 | | 1981 | | 1982 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | N | D | N | D | N | D | N | D | N | D | N | D | N | D | N | D | N | D | N |
| Feb | | | | | | | | | 1 | 1 | | | | | | | | | | |
| Mar | | | | | | | | | | | | | | | | | | | | |
| Apr | | | 3 | | | 1 | 4 | 1 | 3 | 1 | 4 | | 1 | | 3 | 1 | 4 | 1 | 3 | 1 |
| May | | | 2 | 1 | 3 | 1 | 5 | 1 | 7 | 1 | 4 | 1 | 9 | 2 | 3 | 1 | 4 | 1 | 3 | 1 |
| Jun | 3 | 1 | 6 | 1 | 2 | 2 | 4 | 1 | 6 | 1 | 4 | 1 | 4 | 1 | 4 | 1 | 5 | 1 | 1 | 1 |
| Jul | | | 2 | | 5 | 1 | 4 | 1 | 4 | 1 | 4 | 1 | 4 | 1 | 4 | 1 | 4 | 1 | 2 | 1 |
| Aug | 3 | | | | 4 | 1 | 4 | 1 | 3 | 1 | 5 | 1 | 8 | 2 | 5 | 1 | 3 | 1 | 2 | 1 |
| Sep | 4 | | 1 | | 3 | 1 | 3 | 1 | 1 | 1 | 4 | 1 | 3 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| Oct | | | 1 | 1 | 4 | 1 | | 1 | | | 3 | | 3 | 1 | 5 | 1 | 3 | 1 | 1 | 1 |
| Total Dives | 10 | 1 | 15 | 3 | 21 | 8 | 24 | 7 | 25 | 7 | 28 | 5 | 32 | 8 | 27 | 7 | 26 | 7 | 13 | 7 |
| Time (min) | 445 | 71 | 576 | 220 | 949 | 369 | 907 | 428 | 1,035 | 275 | 799 | 249 | 718 | 315 | 647 | 3.0 | 708 | 225 | 266 | 180 |

discharge structures, and two day dives in reference areas (one north and one south of the plant) (Fig. 1). Station names were abbreviated as follows: south intake station - SI, middle intake station - MI, north intake station - NI, south discharge station - SD, north discharge station - ND, south reference station III - SR-III, south reference station II - SR II, south reference station I - SR-I, north reference station III - NR-III, north reference station II - NR-II, and north reference station I - NR-I.

Dives were separated into two categories: standard series dives (those which were performed to satisfy technical specifications) and supplemental dives. Standard series dives were conducted according to fixed procedures which described the area examined by divers, observational and sampling techniques, and recording of data. The formats for supplemental dives were flexible in response to the objectives of the dive.

During standard series dives, two divers equipped with scuba swam side-by-side and either 1 or 2 m apart. Divers made observations and collected samples at the intake structure stations by swimming around the top (61 m in circumference) and base (78 m in circumference) of the structure. While swimming, each diver examined a plot of 2 m in width; the areas examined on top and around the base of the structures were approximately 244 $m^2$ and 312 $m^2$, respectively. In addition, divers swam a 10-m transect along the north side of the south intake structure base following an anchored line placed there for the duration of the study. While swimming a transect along this line, each diver examined adjacent plots 1 m in width, resulting in observations collected from 1 x 10 m (10 $m^2$) plots. These observational efforts in measured areas provided a quantified data base. Swims and observations at the discharge stations were conducted in exactly the same

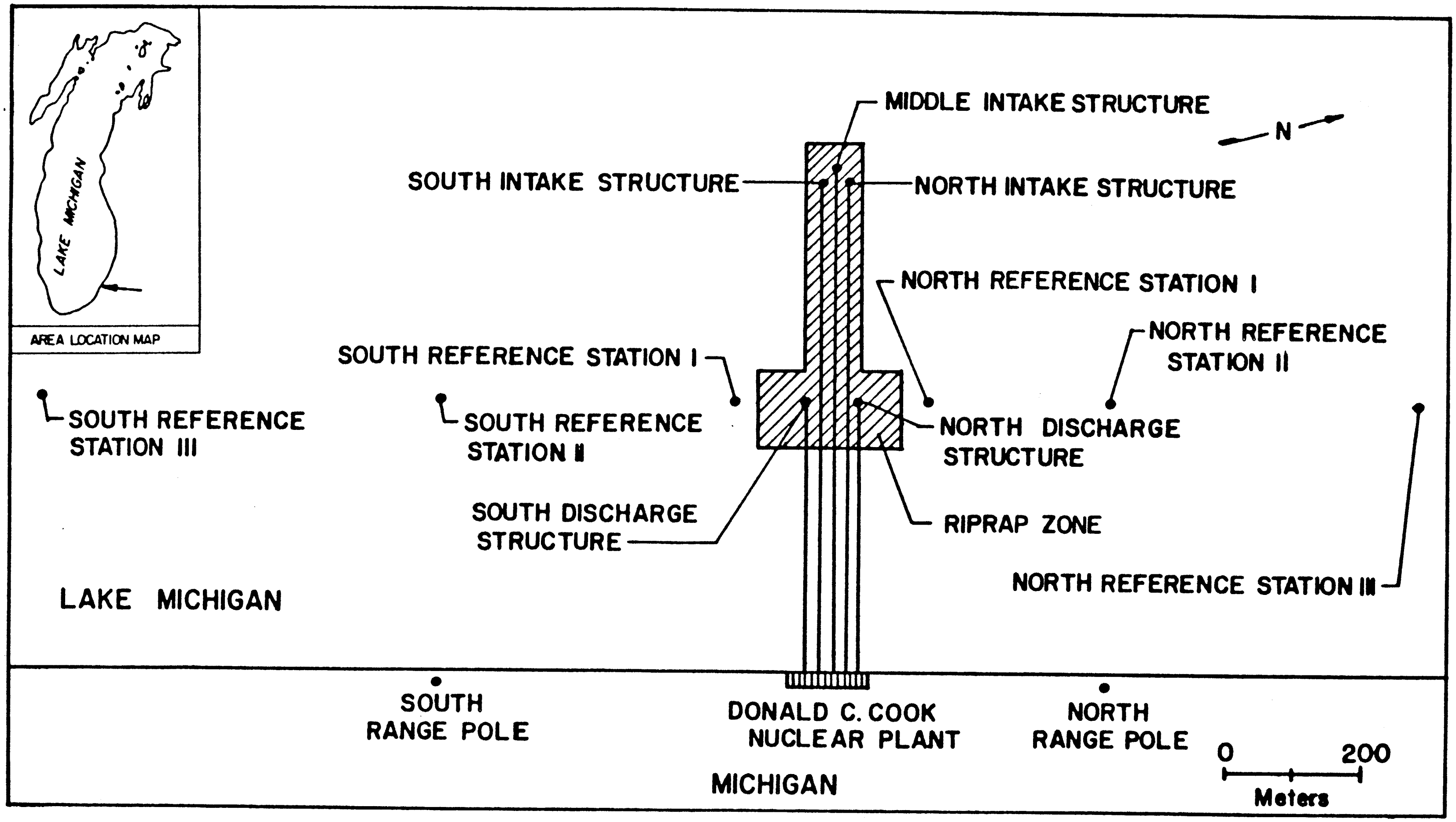


Fig. 1. Scheme of the Cook Plant study area in southeastern Lake Michigan, 1973-1982, showing locations of the scuba-monitored intake, discharge, and reference structures and stations. Stippled area represents approximate dimensions of riprap zone. Depths at intake, discharge, and reference stations were 9 m, 6 m, and 6 m, respectively.

manner as described for the intake structure stations. Areas examined on top (213 $m^2$) and around the base (256 $m^2$) of the discharge structures differed slightly in size from areas examined at the intake structures; however, transect swims along anchored lines at the two locations were conducted identically. Often, but not always, areas in addition to those described were examined during a dive. This was done to increase the total area examined in the vicinity of the plant structures.

At reference stations north and south of the Cook Plant (outside riprap zone in Fig. 1), two 1 x 10 m (10 $m^2$), side-by-side transects were swum parallel to shore in line with the discharge structures. At each reference station, a 10-m line was temporarily anchored for the duration of the transect swim and divers swam out to the full extent of the anchored line. In addition to the two 10-$m^2$ plots examined at a reference station, a 5- to 10-min swim was conducted parallel to shore and toward the discharge structures, following completion of each 10-m transect swim. The 10-m transect swims at the reference stations provided quantified data to compare with those obtained within the plant-structure area (stippled zone in Fig. 1). The 5-10-m swims increased the area examined at the reference stations.

The previously described stations and observational methods comprised our monthly standard series sampling effort. Whenever possible, this complete standard series effort was conducted April through October, 1975-1982.

Occasionally, bad weather or other unsafe diving conditions forced a reduction in this standard series sampling effort, particularly at the beginning and end of the field season. Also, over the duration of the study several basic alterations occurred in the standard series diving effort. As noted earlier, 1973-1974 diving preceded the environmental monitoring

specifications and slight differences occurred in diving efforts and techniques. During mid-1977, two-unit operation was achieved and water was discharged from both structures. Consequently, this area became unsafe for divers to enter and the standard series dive at this location was eliminated. Occasionally after this, when water was not being discharged from one of the structures, supplementary dives were made in this area. Finally, in June 1982, the technical specifications for environmental monitoring were altered and the monthly standard series diving was reduced to one day and one night dive in the vicinity of the south intake structure.

Observations were made following a prescribed format (Fig. 2) and were recorded underwater on water-resistant paper. Occasionally, observations were committed to memory and transcribed at the surface or dictated in a tape recorder for later reference. Observations made by both divers during non-transect swims (e.g., swims around the top and base of the structures, 5- 10-min swims at reference stations, and during supplementary dives) were pooled and discussed as total observations, observations per unit area ($m^2$), or as subjective descriptions of abundance. Transect observations were pooled and a mean and standard error (SE) calculated. For most data, numbers were expressed as numbers per 10 m, 100 m, or 1,000 m to avoid fractional units.

Although data were collected in both a qualitative (descriptions or numerical estimations) and quantitative (counts) manner, suspected violations of assumptions associated with normal-based statistical analyses precluded reliable parametric analysis (see Dorr and Jude 1980a for a discussion of these violations as they pertain to underwater observations and studies). Therefore, analytical procedures were limited to subjective interpretation of data, and development and interpretation of ranked orders of abundance.

Observer ______ Location ______ Depth (ft) ______

Temp: Sur ______ Bot ______ Swell action (bottom): NO YES Visib ______

Turbid: V LOW LOW MED HI V HI Current: NO YES; From ______ Speed ______

Bottom Comp (%): Silt ______ Sand ______ Gravel ______ Rock ______ Floc (mm) ______

Organic debries (Num/Den): ALGAE ____/____ DUNE GRASS ____/____ CHIPS ____/____

TERR. PLANTS ____/____ BARK ____/____ LEAVES ____/____ TWIGS ____/____

BRANCHES ____/____ TRUNKS ____/____ STUMPS ____/____ CLAM SHELLS ____/____

UNID PLANT ____/____ UNID ANIML ____/____ OTHER ____/____

Inorganic debris (Item, Num, Den): ______

Ripple marks: From: ______ Ht ______ Wdth ______ Len ______ Scour: NO YES ______

Loose algae: NO YES; Color ______ Size ______ Num/Den ______

Descr: ______

Periphyton: NO YES; Color ______ Len ______ % Coverage ______

Descr: SPARSE MED LUXURIANT ______

Gastropods: Num Shells ______; Live: NO YES; Num/Den ______

Descr (location, behav) ______

Clams: Num Shells ______; Trails: NO YES (Descr) ______

Live: NO YES; Num/Den ______ Descr ______

Crayfish: Dead; NO YES (Num) ______ Live: NO YES Num/Den ______

Descr (size, location, behav) ______

Fish eggs: NO YES; Location ______ Substrate ______

Num/Den ______ Rel. size ______ Color ______

% Clear ______ % Opaque ______ % Fungus ______ Other ______

Misc invert. (sponge, hydra, bryozoa, insects, crustaceans) ______

| Fish | Number | Density | Size | larv. YOY juv. adt. | Location | Behavior |
|---|---|---|---|---|---|---|
| SS | | | | | | |
| | | | | | | |
| JD | | | | | | |
| | | | | | | |
| AL | | | | | | |
| | | | | | | |
| YP | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

Numerical estimating code: Actual count or; Few (F) = 1–10 Many (M) = 11–50 Numerous (N) = 50–100 Abundant (A) = 100+ Very abundant (T) = 1000+

Comments:

Fig. 2. Prescribed format in which observations and measurements were recorded underwater on water-resistant paper during dives in southeastern Lake Michigan near the D. C. Cook Nuclear Plant, 1973-1982.

Observations and findings presented are based on objective and subjective analysis of quantified data, tempered by our qualitative data, general knowledge of the study area, and interpretation of the literature.

Dorr and Jude (1980a) discussed limitations associated with underwater visual assessments which include equipment and personnel training limitations and physical and psychological stress, all of which serve to reduce the accuracy and precision of observational data. Under conditions of limited visibility (often less than 3 m in the study area), abundance of pelagic organisms is usually underestimated by divers, particularly for highly mobile animals such as large fish. Where substrate is uneven, abundance of demersal or cryptozoic organisms may also be underestimated. Through standardization of our observational techniques, we attempted to obtain at least consistently biased (underestimated) parameter estimates where the error was proportional to the true population size.

Finally, Miller (1956) described the plateau effect which is related to perceptual handling of simultaneously presented stimuli. Shaw (1975) discussed implications of this plateau effect related to fish schooling and "flash expansion" of schools to present multiple moving targets and promote predator avoidance. In a sense, a diver is also a predator subjected to the confusing effect of these avoidance responses. Experience has shown that the visual plateau for divers ranges from 8 to 15 targets when present simultaneously, depending on visibility and duration of the observation period. As a consequence, we developed a standardized code for estimating numbers of objects in a consistent manner. They included: few = 1-10, many = 10-50; numerous = 50-100, abundant = >100. When pooling data (counts) such as these, estimates could be averaged (e.g., few + many = 1-10 + 10-50, or 5 + 30

= 35) or lower (1 + 10 = 11) and upper (10 + 50 = 60) limits placed on parameter estimates. Small aggregations of animals or objects were estimated or counted in total, large aggregations were visually partitioned and the number of items in a single partition counted or estimated and multiplied by the number of partitions to obtain an estimate of total number. These estimates were used during subjective evaluation of fish abundance based upon combined counted and estimated numbers.

The preceding discussion underscores our efforts to develop a continuous and consistent data base. Sampling locations were examined in a spatially and temporally consistent manner. Observational targets (Fig. 2) and efforts were standardized. Subjective descriptions (Fig. 2) and numerical estimation techniques were also standardized and learned by divers. Finally, to reduce variation associated with differences in personal diving techniques and capabilities, the senior author performed all but two months of diving during the entire study. Therefore, about one half of the observational data base included no diver-to-diver variation.

The operational and observational diving techniques used during this study were developed over a 10-yr period 1973-1982. Many of these techniques are described in other underwater studies that we have conducted in the Great Lakes, the results of which are often related to this study. They include: Dorr (1982), Dorr and Jude (1980a, 1980b), Dorr et al. (1981a, 1981b), Jude et al. (1981a, 1982), Rutecki et al. (1983, 1985), Schneeberger (1982), and Schneeberger et al. (1982).

During June 1974, and April-October 1975-1981, divers collected samples of periphyton from the top of the south intake structure and riprap surrounding the base of the structure. Periphyton was scraped from the

structure with a putty knife into a plastic mason jar. Efforts were directed toward collection of an adequate-sized sample; no attempt was made to sample a quantified or consistently-sized area. A small piece of riprap about 4 cm in diameter which supported a noticeable amount of periphyton was selected and placed in a second jar. These samples were preserved in 10% formaldehyde for laboratory analysis, but because of time constraints, only the samples collected from the intake structure were examined. In the laboratory, the sample of scrapings was stirred thoroughly, and a subsample was removed for wet-mounting in water. Algal identifications were made at 400-600X using a Leitz-Wetzlar Ortholux microscope. Taxa identified in these wet-mounts became the yearly lists of periphyton collected from the Cook Plant area.

Data used for comparison with diving observations were derived from companion studies on impinged fish (Thurber and Jude 1984, 1985) and field-collected fish (Tesar et al. 1985, Tesar and Jude 1985). Impinged fish were collected and processed every day during 1975 and every fourth day during 1976-1982. Fish were sampled in Lake Michigan using seines, trawls, and gill nets at a variety of stations from April-November, 1973-1982.

# RESULTS AND DISCUSSION

## PHYSICAL FEATURES

### Waves and Currents

#### Surface Waves

The fetch of Lake Michigan ranges from about 100 km west to about 350 km north. For large lakes such as this, the maximum wave height (h) is related to the fetch (x) of the lake as follows: $h = 0.105x$ (Mortimer 1975, Wetzel 1975). Based on this, maximum wave heights at the study site would range from 3:3 m from the west to 6.2 m from the north.

We observed storm waves with a cycloid diameter or height (trough-to-crest distance) in excess of 4 m, while wave heights of 1-2 m were common during periods of onshore winds. However, it was unsafe for us to dive when wave heights exceeded 1.5 m; therefore, our observations were biased toward conditions extant during quiescent periods in the lake.

Wetzel (1975, p. 94) stated that for travelling surface waves with a cycloid cross-sectional path, "the decrease of vertical movement (of the water) with increasing depth can be approximately described as a halfing of the cycloid diameter for every depth increase of $\lambda/9$", where $\lambda$ is the wavelength measured as crest-to-crest distance. Wetzel further stated that the ratio of amplitude to wavelength is highly variable from 1:100 to 1:10, but that except at shallow beach areas, wave lengths of short surface waves are less than the depth. Given this, the wavelength of a wave 1.5 m high should not exceed 10 m when water depth is less than 10 m. For a wave with a height of 1.5 m and and a wavelength of 9 m (as might have occurred during our dives at the 9-m stations), the vertical displacement of water on the bottom should be about 3 mm. On top of the Cook Plant intake structures, which are

about 4 m below the surface, the vertical displacement of water should be about 90 mm. These calculations are in agreement with conditions that we observed during dives in the study area. If surface waves exceeded 1 m in height, some water displacement was noticeable on the bottom at all 6- and 9-m stations. Water displacement was usually evidenced by a swaying of the periphyton or sloshing movements of surficial floc. On top of the intake or discharge structures this movement was greatly accentuated relative to conditions on the bottom. Because the riprap was mounded from lake bottom level at its periphery to several meters off bottom at the base of the intake and discharge structures, the movement of water caused by surface wave action attenuated as divers swam from the structures across the riprap and down to level bottom. Movement of water on the bottom at <9 m occurred when surface waves were less than 1 m high, but the effects were unnoticeable to divers.

These observations suggest that circulation of water and resuspension of surficial sediment and flocculent organic material occurs through surface wave action. The threshold for these effects probably occurs when wave heights are between 0.5-1.0 m; effects increase rapidly with increasing wave height. Evidence that the riprap traps sediment will be presented later. This factor in combination with surface wave action probably contributed to the increased levels of suspended materials observed by divers near bottom in riprapped areas relative to the surrounding sand areas, when lake surface conditions were rough. Barres et al. (1984) noted elevated levels of particulates in phytoplankton samples collected from the Cook Plant forebay during periods of stormy weather and nearshore turbulence. As discussed later, plant intake water was often noted by divers to be drawn from the bottom of the water column at the base of the intake structures. The resuspension of surficial

material noted by divers during and immediately after periods of rough lake conditions may account for the elevated levels of particulates noted in these samples. Rossmann et al. (1982) suggested that elevated concentrations of orthophosphate and dissolved silica in water samples collected in the study area may also have resulted from storm-induced turbulence.

These observations indicate that surface wave action increased the amount of suspended material in the riprap areas, relative to surrounding areas. Attached algae and invertebrates (sponge, bryozoans, Hydra); benthic invertebrates, such as worms, insect larvae, snails, and crayfish; and fish with demersal life stages concentrated in the riprap areas were exposed to effects of this increased suspension. Such effects may have included increased siltation and impairment of filter feeding. Surface wave action undoubtedly promoted circulation of water in and around the riprap. The rise of the riprap off bottom in combination with its many interstices permitted surface wave action to more effectively perfuse this substrate. This in turn would improve the availability of oxygen and exchange of gases, while serving to continually remove floc from the surface of the substrate.

Currents

Wind friction and atmospheric pressure changes result in seiches, differential heating of the lake, diffusion of dissolved materials from the sediments, influx and outflow of water, and geostrophic (e.g., Coriolis) effects (Mortimer 1975). In Lake Michigan, surface currents often circulate in large swirls or gyres (Ayers et al. 1958) which in turn are subject to modifications by standing wave motions. Lake basin morphometry also influences direction and speed of surface water currents. Although general current patterns may be

established in large bodies of water such as the southern basin of Lake Michigan, current velocity at any given point may vary with local conditions. This is particularly true for the inshore region where local effects such as presence of offshore winds or sand bars may influence current flow.

Studies on currents were conducted in 1975 and 1978 (Indiana & Michigan Power Company 1975, 1976; ETA 1980) at locations about 600 m north and south of the Cook Plant at the 3- and 6-m depth contours. Generally, current speeds measured during 1975 ranged from 6 to 12 cm/s (0.2-0.4 fps) with a maximum speed approaching 60 cm/s (2 fps). Currents tended to flow to the north, although considerable day-to-day variation occurred. These data suggest that considerable variability existed in both current speed and direction in space and time. Mortimer (1975) has found that current vectors nearshore are predominantly shore-parallel, while offshore, the clockwise rotating current vectors of Poincâre waves dominate the lake.

Efforts by divers to establish general current direction and speed at a given location were unsuccessful. Considerable variability was measured among locations separated by only 200 m as well as differences at various depths in the water column. Consequently, no attempt was made by divers to assess current velocities, although effects of currents were recorded when observed.

Absence or presence of currents was best observed by the horizontal transport of suspended material past a stationary diver. When surface waves exceeded 0.5 m in height, vertical displacement of the water obscured the horizontal movement of suspended material at depths less than 3 m. When currents were present, horizontal movement of suspended material could be discerned within 1 m of the bottom at 6 m and 9 m, regardless of wave heights at the surface. This was the result of the rapid attenuation of vertical

displacement of water with increasing depth. In areas where sediment accumulated, such as localized depressions in the sand observed at the reference station or at the periphery of the riprap field, both current and surface waves acted to resuspend sediment.

In general, current flow and direction appeared to be influenced by proximity to the intake and discharge structures at the surface and on the bottom. Strong currents were encountered throughout the water column at stations 100 m north and south of the respective discharge structure during discharge of water. As best as could be determined, the direction of flow was always away from the structure. Strong eddy currents were encountered during dives at a station located in line with, and mid-way between, the two discharge structures. But at the reference stations located 900 m north and 1200 m south of the Cook Plant, no effect of plant water discharge on local water current was discerned.

Within the riprap area, pronounced currents associated with plant water circulation obscured any general current patterns noticeable to divers. Large differences in the force of the intake current could be felt at different points around the base of each structure. These differences ranged from currents that were almost undetectable to those that were difficult to swim against. The direction and speed of the natural lake current and the recirculation patterns established between the intake and discharge structures influenced the direction and strength of the intake current and the withdrawal of water from various levels of the water column.

In both riprap areas and on open lake bottom increased rugosity of the bottom profile acted to reduce current speed within a few centimeters of the bottom. This observation is in keeping with the existence of a boundary layer

of slack water known to exist as a function of vertical relief dimensions and variability and of current force and direction. Both riprap and large ripple marks would contribute to variability in vertical relief and current flow at the water-sediment interface.

## Thermal Effects

Water temperature regimes encountered during our underwater studies paralleled those characteristic of southern Lake Michigan. Water temperatures were 4-8°C during April and increased rapidly during May-June. Temperatures less than 10°C were rarely encountered during June-September. During fall, temperatures declined and reached 10°C during late October-early November as determined from other dive studies in the region (Dorr and Jude 1980a, Dorr et al. 1981b).

Divers experienced three major thermal effects. The first was vertical thermal stratification during June-August. It was common to encounter a 1-m thick layer of very warm water at the surface, particularly when the lake surface was calm. An abrupt drop in water temperature could be felt on exposed skin as divers descended through this layer. Temperatures in the adjoining layer remained nearly constant until 1-2 m off bottom. At this point, a second abrupt thermal decline was noticed. This layer of cold water on the bottom was often more turbid than overlying water, and contained higher amounts of suspended particles. It was believed that these were relatively distinct thermal layers and that mixing of water among layers was reduced relative to homothermal conditions. Observation of the distinct cold nepheloid layer on bottom supports this contention.

The second effect experienced by divers was that of horizontal thermal stratification. This condition was again encountered during the warm-water months and was particularly noticeable during the 5-min swims at reference stations. Divers often swam through water masses of different temperatures; thermal interfaces were usually distinct and only a few meters thick. Because all swims were conducted on the bottom at 6 m little is known of conditions in mid-water. It is possible that isolated masses of cooler water were present on the bottom and surrounded by warmer water, perhaps as a result of uneven development or breakdown of vertical stratification following a change in lake conditions (e.g., surface waves, currents, upwelling).

The final thermal effect encountered by divers was summer upwelling of cold water inshore following periods of strong offshore winds. Unusually cold water was occasionally encountered during typically warm-water periods, i.e., July or August. On some occasions, water temperatures declined considerably during diving which occurred over a 2-day period. Again, cold-water upwellings were often accompanied by increased turbidity and pronounced decreases in underwater visibility.

Because of lake size and its gentle sloping bottom, the major thermocline between the epilimnion and the hypolimnion lay well offshore of the study area during the period of maximum vertical thermal stratification. During occasional dives in deep water (>12 m), a distinct thermocline was encountered along with a large difference in temperature between the epilimnion and hypolimnion.

Surficial Features

Presence of riprap and in-lake plant structures created artificial features and atypical habitat. Most of the lake bottom in inshore southeastern Lake Michigan is composed of coarse- to fine-grained sand with occasional areas of pebbles, and presents a flat, unbroken profile. Only isolated rocks and an occasional log or branch were encountered during our studies. Dorr (1982), Dorr and Jude (1980b), and Jude et al. (1978) conducted extensive diver surveys of areas containing rough substrate of natural (moraines, clay banks) and artificial (reefs, utility structures, harbor breakwalls) origin from Muskegon, Michigan, south to Michigan City, Indiana. Areas of rough substrate were isolated within the total inshore system and represented only a small portion (<1%) of the total inshore area.

Ripple marks and occasional large depressions were observed at the reference stations and during swims along the 6-m contour. The dimensions and direction of ripple marks observed 1000 m north (Station III) and 1200 m south (station III) of the plant were measured and recorded during 1973-1982 (Table 2). Most often, ripple marks were generated from a westerly-to-northerly direction (quadrant IV - 270-360°). This was the situation during 84% of the dives at the north station, and 74% of the dives at the south station. The slight reduction (10%) in frequency of generation from the fourth quadrant observed at the south station was probably created by the riprap north of the south station. This hypothesis is supported by our observations that ripple marks were consistently smallest at the south reference station (station I) closest to the riprap. Discharge of water in a north and westerly direction combined with the "reef-like" barrier that the riprap and discharge structures presented, undoubtedly acted to diminish the

Table 2. Direction of generation (quadrant), height (trough-to-crest), and width (crest-to-crest) of ripple marks observed by divers in reference areas north and south of the D. C. Cook Nuclear Plant, during some months from 1973 to 1982. Quadrant: I = north to east (0-90°); II = east to south (90-180°); III = south to west (180-270°); IV = west to north (270-360°); Asym = asymmetric (no clear direction of generation). Dimensions are in cm. Blanks indicate no data.

| | North Reference Areas | | | South Reference Areas | | |
|---|---|---|---|---|---|---|
| Month | Quadrant | Height | Width | Quadrant | Height | Width |
| 1973 | | | | | | |
| Sep | IV | 17 | 61 | | | |
| 1974 | | | | | | |
| Apr | IV | 3 | 15 | | | |
| Jun | | | | IV | 3 | 18 |
| Jul | | | | IV | 4 | 10 |
| 1975 | | | | | | |
| May | IV | 5 | 15 | IV | 4 | 17 |
| Jun | III | 1 | 11 | | | |
| Jul | III | 4 | 10 | III | 5 | 31 |
| Aug | I | 3 | 9 | III | 4 | 13 |
| Sep | IV | 6 | 20 | | | |
| Oct | I | 5 | 9 | IV | 4 | 19 |
| 1976 | | | | | | |
| Apr | III | 11 | 75 | II | 2 | 5 |
| May | III | 4 | 15 | III | 4 | 14 |
| Jun | IV | 5 | 16 | IV | 4 | 5 |
| Jul | IV | 2 | 8 | IV | 4 | 6 |
| Aug | I | 6 | 15 | IV | 2 | 6 |
| Sep | IV | 6 | 8 | | | |
| 1977 | | | | | | |
| Apr | IV | 13 | 100 | | | |
| May | IV | 2 | 18 | IV | 2 | 11 |
| Jun | IV | 4 | 10 | Asym | 1 | 6 |
| Jul | IV | 3 | 10 | IV | 2 | 5 |
| Aug | IV | 2 | 5 | IV | 3 | 15 |

(Continued).

Table 2. Continued.

| | North Reference Areas | | | South Reference Areas | | |
|---|---|---|---|---|---|---|
| Month | Quadrant | Height | Width | Quadrant | Height | Width |
| 1978 | | | | | | |
| Apr | | | | III | 5 | 15 |
| May | III | 4 | 20 | Asym | <1 | <1 |
| Jun | IV | 6 | 25 | III | 5 | 20 |
| Jul | IV | 5 | 18 | IV | 2 | 10 |
| Aug | IV | 3 | 15 | IV | 3 | 15 |
| Sep | IV | 25 | 50 | IV | 2 | 5 |
| Oct | IV | 3 | 10 | | | |
| 1979 | | | | | | |
| May | IV | 4 | 20 | IV | 4 | 20 |
| Jun | IV | 5 | 15 | IV | 4 | 12 |
| Jul | IV | 3 | 10 | IV | 5 | 150 |
| Aug | IV | 5 | 20 | IV | 5 | 18 |
| Oct | IV | 3 | 15 | IV | 2 | 6 |
| 1980 | | | | | | |
| Apr | IV | 4 | 12 | IV | 6 | 20 |
| May | IV | 14 | 90 | Asym | 2 | 10 |
| Jun | IV | 5 | 15 | IV | 3 | 15 |
| Jul | IV | 15 | 60 | IV | 5 | 8 |
| Aug | IV | 4 | 12 | IV | 4 | 15 |
| Sep | IV | 4 | 6 | IV | 2 | 10 |
| Oct | IV | 3 | 5 | IV | 2 | 6 |
| 1981 | | | | | | |
| Apr | IV | 50 | 100 | IV | 3 | 6 |
| May | IV | 2 | 6 | IV | 2 | 6 |
| Jun | IV | 20 | 60 | IV | 2 | 6 |
| Jul | IV | 3 | 10 | IV | 2 | 6 |
| Aug | IV | 2 | 6 | IV | 2 | 6 |
| Sep | IV | 6 | 10 | IV | 4 | 8 |
| Oct | IV | 4 | 8 | I | 4 | 6 |
| 1982 | | | | | | |
| Apr | IV | 8 | 10 | IV | 6 | 6 |
| May | IV | 12 | 15 | Asym | 4 | 10 |

strength of waves and currents approaching from that direction, which is the prevailing direction of approach at this location on the lake. In general, ripple marks were smallest and most asymmetrically developed at reference stations (stations I and II) closest to the riprap and discharge area.

Very large ripple marks with amplitudes (heights) exceeding 10 cm were occasionally observed at the two most northerly reference stations. These marks often had wavelengths of 50-100 cm, and extended for 10 m or more along the bottom. They were always generated from the 270-360° quadrant (quadrant IV - west-north), and were never observed at south reference stations. These large marks usually occurred in isolated patches along the 6-m contour and were separated by extensive areas containing much smaller ripple marks. Often these smaller marks were generated from a different direction and cross-hatched the large marks. Most likely, these large ripple marks were the remnants of marks generated during conditions of high winds and large surface waves coming from a westerly to northerly direction. Large marks were never observed at the north reference station (station I) closest to the discharge area, again probably a result of the disruptive effect of the north-westerly directed discharge current on incoming waves. In fact, the disruption of surface waves by the plant's water discharge is observable from shore.

The other surficial feature of the bottom observed in the vicinity of the reference stations was the presence of localized depressions in the lake bottom. These depressions were only observed during swims parallel to shore between north reference station II and station III. During the 5-10-min swims, divers occasionally encountered depressions about 1 m deep and 5-10 m across; because the third dimension was not measured, the actual shape of these depressions is not known. We suspect that they may have been roughly

oval in shape with the long axis oriented more closely perpendicular to shore than the short axis. These depressions were surficial features of the bottom that were distinctly different from the major troughs that were located between the major sand bars. One possibility is that these depressions were trenches or cuts across these major bars and that the depressions connected adjoining troughs. Another possibility is that the depressions were remnants of old troughs that had been mostly filled in during the relocation of a bar. These features are not unique to the Cook Plant area, since we observed them during other underwater studies in inshore southeastern Lake Michigan.

## Sediment

Qualitative microscopic analysis of the flocculent ("floc") layer of material overlying the riprap and sand revealed it to be composed primarily of sediment, diatom tests, and some organic detritus (primarily algae). The thickness of this layer ranged from complete absence to about 10 mm; a layer 2-3 mm thick was typical of the area (Table 3).

When present, similar amounts of floc were observed in both reference areas and on the riprap. However, only once, in April 1982, was floc totally absent from the riprap surrounding the intake structures, whereas, complete absence of floc in reference areas was more common (8 occurrences at north reference station III, 11 occurrences at south reference station III). Observations of floc deeper than 10 mm were made on two occasions north of the plant and once south of it. The floc layer on the riprap was never thicker than 6 mm between 1975 and 1982.

We attribute the more continuous presence of floc on riprap compared with sand to be the result of the better trapping action of the riprap surface.

Table 3. Depth (mm) of flocculent surficial sediment measured on riprap surrounding the D. C. Cook Nuclear Plant intake structures and at reference stations north and south of the plant, 1973-1982. T (trace) = detectable, but unmeasurable. Blanks indicate no measurements made.

| Month | Area: Intake | N. Reference | S. Reference |
|---|---|---|---|
| **1973** | | | |
| Jun | | | <5 |
| Aug | <5 | | |
| Sep | <5 | <5 | |
| **1974** | | | |
| Apr | >10 | 5-10 | |
| May | 5-10 | | |
| Jun | <5 | | |
| Oct | 5 | | |
| **1975** | | | |
| May | 6 | <5 | |
| Jun | <5 | T | |
| Jul | 4 | 2 | |
| Aug | 3 | T | 0 |
| Sep | 3 | 0 | |
| Oct | 2 | 0 | 0 |
| **1976** | | | |
| Apr | 2 | 2 | 2 |
| May | 3 | 20 | 3 |
| Jun | 2 | 1 | 1 |
| Jul | 3 | 2 | 2 |
| Aug | 2 | 0 | 5 |
| Sep | 2 | 2 | |
| Oct | 4 | | |
| **1977** | | | |
| Apr | 3 | 15 | |
| May | 3 | 2 | 0 |
| Jun | | 2 | 0 |
| Jul | 3 | 0 | 0 |
| Aug | 4 | T | 0 |
| Sep | 2 | | |

(Continued).

Table 3. Continued.

| Month | Area | | |
|---|---|---|---|
| | Intake | N. Reference | S. Reference |
| **1978** | | | |
| Apr | 5 | 4 | 0 |
| May | 3 | 3 | 3 |
| Jun | 2 | 3 | 2 |
| Jul | | 8 | 4 |
| Aug | 1 | 2 | 2 |
| Sep | 2 | | 4 |
| Oct | 3 | 1 | |
| **1979** | | | |
| Apr | 1 | | |
| May | 2 | 3 | 5 |
| Jun | 3 | 8 | 3 |
| Jul | T | 1 | 3 |
| Aug | 4 | 2 | 2 |
| Sep | 1 | 0 | 0 |
| Oct | 1 | 2 | 0 |
| **1980** | | | |
| Apr | 2 | 2 | 2 |
| May | | 3 | 4 |
| Jun | 1 | 2 | 2 |
| Jul | | 0 | 0 |
| Aug | | 2 | 3 |
| Sep | 2 | 0 | 20 |
| Oct | 2 | 2 | 2 |
| **1981** | | | |
| Apr | 2 | 2 | 4 |
| May | 2 | 5 | 4 |
| Jun | 2 | 2 | 5 |
| Jul | 2 | 0 | 2 |
| Aug | 4 | 2 | 2 |
| Sep | 2 | 3 | 4 |
| Oct | 1 | 1 | 0 |
| **1982** | | | |
| Apr | 0 | 8 | 6 |
| May | 3 | 2 | 3 |
| Aug | 4 | | |
| Oct | 2 | | |

The uneven surface of individual clasts and the presence of periphyton caused floc to be retained more effectively than on the smooth surface of the sand bottom. Two general observations support this contention: (1) floc accumulated in the troughs of the ripple marks, and not on the sides or crests, and (2) surface wave action often caused movement of floc on the sand bottom but not on the riprap. Rarely did floc accumulate on the sides or crests of ripple marks. Most often, it was carried into the troughs by water movement. It was noted earlier that surface wave action could be felt on the bottom at 6 m when waves exceeded 1 m in height. Also, the threshold for noticeable water movement occurred when waves were 0.5-1.0 m in height. When surface waves were 1 m, a slight oscillation or movement of the floc in the troughs of ripple marks was apparent. Under these same conditions, the periphyton on riprap was observed to sway, but no movement of the floc could be seen.

Additional evidence that uneven surfaces trapped sediment more effectively that smooth surfaces was provided by the occasional deep accumulations of floc in depressions observed in the sand bottom in the north reference area (see previous section - Surficial Features). Floc 10-20 cm deep was measured in some of these depressions (Table 3). Suspended material, transported along the bottom, probably encountered these depressions where water velocities were reduced resulting in this material being deposited in thick layers. In a sense, these large depressions were analogous to small pockets or interstices in the surface of the riprap. A small trough (1-2 m wide and less than 1 m deep) in the sand bottom adjacent to the riprap often formed along the perimeter of the riprap. Quite often, floc accumulated in this restricted area to depths of 10-20 mm. Most likely, this was the result of a small area of stagnant water created by the barrier which the riprap

imposed as it rose off the bottom at this point. Observations made during studies of other areas of naturally formed sand (Jude et al. 1978, Dorr and Jude 1980b), rock or clay bottom (Dorr 1982), and artificial substrates (Dorr et al. 1981b, Dorr 1982) confirm that rugose surfaces trap sediment more effectively than smooth surfaces.

There appeared to be a direct relationship between absence or presence of floc and water depth. In this study and others (Dorr 1974, Dorr and Miller 1975, Dorr 1982), floc was rarely observed at depths less than 6 m. However, it was always present at 12 m or more. Seibel et al. (1974) and Rossmann and Seibel (1977) noted a distinct demarcation at 24 m where finer-grained sediment predominated. Its occurrence was a function of depth and severity of nearshore physical processes, including wave action and currents. Our observations, combined with the calculated attenuation of even the largest surface waves observed during any period of several years, suggest that at depths greater than 12 m, the movement of water is not sufficient to sweep even smooth bottom clear of flocculent material, much less rugose surfaces. This observation has significant implications regarding the depth location of structures such as artificial reefs or natural lake trout spawning reefs, where the removal or absence of floc from the surfaces or interstices of the substrate by natural movements of the water is desired.

In a 1977 experiment, we positioned several vertical sediment-collecting tubes 1 m off bottom over Cook Plant intake riprap. Following a 21-day period (25 May-16 June), 74 mm of material was collected in the 3.8-cm diameter tubes. The tubes were constructed to permit diffusion of formaldehyde from an attached reservoir into the collection chamber, thereby preserving the material from decomposition. About 90% of the floc collected was sediment;

the remaining portion was composed of diatom tests and organic detritus. This experiment confirmed the potential for rapid deposition and accumulation of sediment in inshore depressions.

Flocculent material may change the circulation of water, dissolved gas exchange, and sediment oxygen demand (SOD) in microhabitats such as surfaces and interstices of substrates, which might adversely impact biological entities such as incubating lake trout eggs.

## Transparency

Water transparency, the maximum distance between two divers at which they remained visible, was measured on the bottom with a line marked at 0.5-m intervals; values were relatively comparable among riprap and reference stations (Table 4). Highest visibility recorded was 6.8 m at the 9-m intake station, while the lowest was 0.6 m at a north reference station. Typical values were 2-3 m at all stations.

Visibility tended to be highest during summer months (June-August). This was probably the result of summer thermal stratification, followed by depletion of nutrients, and reduced plankton productivity. Also, fewer severe storms and reduced turbulence during summer permitted suspended material to settle. Highest visibilities occurred following a period of one to two weeks of calm lake conditions.

Several patterns were noted in the visibility among stations. Visibilities were usually lower at the two stations closest to the discharge structures (NR-1, SR-1) than at other reference or riprap stations. Also, there was a noticeable decrease in visibility from surface to bottom (6 m) at these two stations. The reduction in visibility at these locations was the

Table 4. Horizontal visibility (m) as measured by divers on the bottom near Cook Plant intake structures (9 m) and in reference areas (6 m) north and south of the plant, 1973-1982. Asterisk (*) shows months when measurements were not made on the same day at intake and reference stations. Measurements at reference stations were always made on the same day for any given month. Omitted months and blanks indicate no measurements made.

| | Area | | |
|---|---|---|---|
| Month | Intake | N. Reference | S. Reference |
| 1973 | | | |
| Jun* | 2.0 | | 2.0 |
| Aug | 4.5 | | |
| Sep | 1.2 | | 1.8 |
| 1974 | | | |
| Apr* | 1.0 | 0.6 | |
| May | 3.8 | | |
| Jun | 3.3 | | 3.3 |
| Jul | | | 1.7 |
| Oct | 1.2 | | |
| 1975 | | | |
| May* | 2.1 | 2.0 | |
| Jun | 7.6 | 6.1 | |
| Jul | 4.5 | 4.0 | 4.5 |
| Aug* | 3.0 | 3.0 | 1.5 |
| Sep | 2.7 | 2.7 | |
| Oct | 2.7 | 2.0 | 2.5 |
| 1976 | | | |
| Apr* | 2.5 | 1.8 | 1.0 |
| May* | 2.0 | 1.8 | 1.2 |
| Jun | 4.0 | 4.5 | 3.0 |
| Jul | 1.5 | 1.5 | 2.0 |
| Aug* | 3.0 | 3.0 | 3.0 |
| Sep | 2.0 | 1.5 | |
| Oct | 3.0 | | |
| 1977 | | | |
| May | 3.0 | | |
| Jun | 6.8 | 6.1 | 6.0 |
| Jul* | 5.0 | 3.0 | 4.5 |
| Aug | 6.0 | 4.0 | 4.0 |
| Sep | 2.5 | 2.0 | 2.0 |

(Continued).

Table 4. Continued.

| Month | Area | | |
|---|---|---|---|
| | Intake | N. Reference | S. Reference |
| 1978 | | | |
| Apr | 1.0 | 1.0 | 1.0 |
| May | 1.0 | 2.0 | 2.0 |
| Jun | 3.0 | 3.0 | 3.0 |
| Jul* | 2.0 | 3.0 | 3.0 |
| Aug | 2.5 | 2.5 | 3.0 |
| Sep | 2.0 | 2.0 | 2.0 |
| Oct | 1.0 | 3.0 | |
| 1979 | | | |
| Apr | 2.0 | | |
| May | 2.0 | 2.5 | 2.0 |
| Jun | 2.0 | 2.0 | 2.0 |
| Jul | 4.5 | 4.0 | 4.0 |
| Aug | 3.0 | 3.0 | 3.0 |
| Sep | 3.0 | | |
| Oct* | 1.3 | 2.0 | 2.0 |
| 1980 | | | |
| Apr | 2.0 | 3.0 | 2.0 |
| May | | 3.0 | 2.5 |
| Jun | 3.0 | 3.0 | 3.0 |
| Jul | 1.0 | 2.5 | 1.5 |
| Aug* | 2.0 | 2.0 | 2.0 |
| Sep* | 2.0 | 2.5 | 2.5 |
| Oct* | 2.5 | 2.0 | 2.5 |
| 1981 | | | |
| Apr | 1.5 | 1.5 | 2.0 |
| May | 2.0 | 2.0 | 2.0 |
| Jun | 3.0 | 3.0 | 3.0 |
| Jul | 2.0 | 3.0 | 1.0 |
| Aug | 3.0 | 4.0 | 3.0 |
| Sep | 3.0 | 2.5 | 2.0 |
| Oct | 1.5 | 1.0 | 2.0 |
| 1982 | | | |
| Apr | 1.5 | 1.0 | 1.0 |
| May* | 3.0 | 3.0 | 3.0 |
| Jun | 4.0 | | |
| Jul | 4.0 | | |
| Aug | 4.0 | | |
| Sep | 3.0 | | |
| Oct | 3.0 | | |

result of increased turbulence and suspension of sediment near the point of water discharge. No effect of plant-induced turbulence and reduced visibility was noted at reference stations farthest from the discharge structures.

On several occasions (Table 4), visibility at intake structures was greater than at reference stations. This situation occurred during summer months when a slight thermal stratification developed inshore (see previous section - Thermal Effects). A warm, clear layer of water occasionally overlaid a narrow band (1-2 m thick) of colder, more turbid water adjacent to the bottom. At reference stations where these layers were undisturbed, visibility was markedly reduced by one-half or more compared to the intake area. The overlying water layer was often drawn down into the lower layer at the intake structures, thus displacing the cooler, more turbid water and accounting for lower visibilities at reference stations. While diving on the bottom around the base of the intake structures, divers often swam in and out of these two water masses. This probably occurred because the water was not drawn evenly from both layers at all points around the structures.

Our studies in other inshore areas of southeastern Lake Michigan revealed that water transparency, measured as underwater visibility, did not vary consistently among locations. Underwater visibilities recorded at the Cook Plant were typical of the area. But, in another study (Dorr 1982) south of the plant near New Buffalo, Michigan, we found visibility on the bottom (6-12 m) in an isolated area of clay substrate and extensive submarine trenches to be consistently lower than the surrounding area, including that of the Cook Plant. This was the result of erosion of the clay substrate combined with relatively stagnant water contained in trenches. The water was usually much more transparent several meters above bottom.

Observations at the Cook Plant and elsewhere in the area suggest that inshore visibility (transparency) is largely a function of water movements or currents that suspend sediment off bottom. During quiescent periods, this material settles and transparency increases significantly. Presence of accumulations of sediment or erodable material such as clay may reduce visibility locally.

## Inorganic Debris

We distinguished between inorganic debris observed in the study area and organic material which was termed detritus. Two general types of debris were noted: that which was deposited during initial construction and subsequent repair of in-lake plant structures, and debris which accumulated as a result of activities unrelated to plant construction and maintenance operations.

A variety of materials was deposited on the riprap during construction including: steel girders and plates, metal pipe, plastic, steel cable, and tires. For the most part, heavy objects remained in place for the duration of the study. Subsequent repair work on these structures (e.g., replacement of broken ice guards on the structures, addition of riprap or cement scour pads, etc.) resulted in accumulation of debris which remained in the area. However, some transport of lighter materials (plastic, tires, containers, etc.) from the area occurred during major storms.

In contrast with the riprap area, debris from plant construction was never observed on the surrounding sand bottom. If such debris were deposited in this area, lighter materials were probably rapidly transported from the area, while heavy objects sank into the bottom and were covered over by sand. The end result was that plant construction debris did not remain exposed in

sand bottom areas for an extended time. In contrast, inorganic debris and organic detritus deposited on the riprap could not sink into the substrate, but snagged on the projections and in the crevices of the rugose substrate and was held in place. This debris served to expand the variety of substrates and habitats available to local biota.

The other general type of debris that was noted in the area was that which resulted from the dumping of trash into the lake. Some of this material (beverage containers, clothing, fishing tackle, household items, etc.) was dumped directly into the area by people fishing from small boats. It was not uncommon to count 20 or more small boats over the riprap area on a summer day. The other source of this trash came from refuse dumped in surrounding areas of the lake or eroded from the beach.

In general, the bulk of this trash was composed of lighter items which were eventually transported from the area. Trash was less abundant in the early spring following the prolonged absence of fishermen from the area coupled with the intense fall and spring storms which swept trash from the area. Evidence of such transport was provided by the occasional observation of such trash at all reference stations. Our observations during this and other studies reveal that while most trash is washed onshore or buried and eventually degraded in the substrate, considerable amounts of litter must be exposed and washed along the bottom of the lake at any given time. We base this observation on consideration of the relatively small areas of the lake bottom observed by divers, and the fairly high frequency at which trash was observed. With the exception of the riprap area itself, accumulations and observations of trash near the Cook Plant were similar to those noted elsewhere in the lake.

While plant construction materials that remained in place on the riprap provided expanded substrate and habitat, the trash did not. Trash was an inevitable result of the intensive use of a small area of the lake by the fishing populace.

## BIOLOGICAL FEATURES

### Organic Detritus

Organic detritus observed in the study area by divers was classified into two groups: microscopic and macroscopic. Microscopic organic detritus was defined as organic material whose original form could not be discerned by the unaided eye. These materials included remains of planktonic organisms or parts of larger organisms that were finely divided, such as shredded plants or decomposed animal tissue. Macroscopic organic detritus included dead algae, parts of plants (e.g., grasses, bark, twigs, limbs, trunks), and dead animals (e.g., crayfish and fish).

Accumulations of sediment greater than 10 mm thick were uncommon but amounts less than 5 mm thick were frequently observed in the study area. No diver-collected samples were analyzed for loss of organic material upon ignition, at which time organic material would be oxidized to carbon dioxide and water. However, in a separate study, analysis of 34 samples collected at depths less than 18 m in the vicinity of the study area showed a mean loss in sample weight upon ignition of 4.3% with a standard deviation of 4.1% (Rossmann and Seibel 1977). Combined with diving observations, these results suggest that both the total accumulation of surficial sediment and its organic component are variable in inshore southeastern Lake Michigan. Typical values for thickness and organic content of inshore surficial sediment are 3-5 mm and

4.3% total weight, respectively. These observations also suggest that small amounts of microscopic organic material are consistently available to benthic detritivores including epibenthic zooplankton, sponges, bryozoans, Hydra, snails, clams, crayfish, insect larvae, and fish. Not surprisingly, all of these organisms were found in the study area, although they were unevenly distributed.

Presence of macroscopic organic detritus was recorded in one of several categories contained in the prescribed record format (Figure 2). Some of these groups were later combined and summarized in six general categories of macroscopic material: algae (A), dune grass (B), shreds or chips of wood (C), twigs and branches (D), tree trunks and stumps (E), and fish (F) (Table 5). Other materials such as mollusc shells, insect larvae exuviae, crayfish, and fish feces were seen on occasion, but not often enough to warrant inclusion in the general summarization of observations. It was not possible to discern or count individual detrital objects. Therefore, only presence (or absence) of detritus within the various categories was noted and summarized as frequency of occurrence (%) among stations and years (Table 5).

Most types of organic detritus were observed at one time or another at all stations. Twigs and branches were most common and were seen at all stations at least once in all years. Clumps of loose algae were seen during 22% and 26% of all dives at the north- and south-reference stations, respectively. Dune grass was noted more often at the reference stations than at the intake or discharge stations. Shreds and chips of wood were consistently seen at all stations, but were observed more frequently in reference areas. The smooth, flat bottom at the reference stations facilitated diver observation of small detrital objects such as algae, dune

Table 5. Frequency of observation (%) of organic detritus on the bottom of southeastern Lake Michigan during standard series dives in the vicinity of the D.C. Cook Nuclear Plant, 1973-1982.[1] Observations of fish (F) are expressed in absolute numbers of fish counted during dives.

| Year and station[2] | No. of dives | Category[3] A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|
| 1973 | | | | | | | |
| NR | 1 | | | 100 | | | |
| SR | 1 | | | | | | 10 AL |
| I | 4 | 25 | 25 | 25 | 25 | | |
| D | 3 | 33 | 33 | | 33 | | 1 YP |
| 1974 | | | | | | | |
| NR | 1 | | 100 | 100 | 100 | | |
| SR | 3 | 100 | | 33 | | | 5 AL |
| I | 9 | | | | | | |
| D | 6 | | 33 | 50 | 50 | 67 | 1 SS, 1 YP, 1 XX |
| 1975 | | | | | | | |
| NR | 6 | 50 | | 67 | 33 | | 1 AL |
| SR | 4 | 50 | | 50 | | | 4 AL, 1 YP |
| I | 11 | | | | 27 | | 1 AL |
| D | 7 | 14 | | 14 | 100 | 43 | |
| 1976 | | | | | | | |
| NR | 6 | | 17 | 67 | 50 | | 1 AL |
| SR | 5 | | 20 | 40 | | | 1 AL |
| I | 12 | | | | 17 | | 1 AL |
| D | 6 | | | 33 | 100 | 33 | 7 AL |
| 1977 | | | | | | | |
| NR | 5 | 60 | 20 | 20 | | | 4 AL, 1 SP |
| SR | 4 | 75 | | | | | 2 AL, 1 SM |
| I | 12 | 8 | | 8 | 17 | | |
| D | 4 | 25 | | 50 | 75 | | 9 AL, 1 CP, 1 SS |
| 1978 | | | | | | | |
| NR | 7 | 29 | | | 14 | | 2 AL |
| SR | 6 | 17 | | 17 | | | 1 CC, 1 XX |
| I | 12 | 8 | | | 8 | 8 | |
| D | | | | | | | |
| 1979 | | | | | | | |
| NR | 7 | 14 | | 29 | 14 | | 2 AL |
| SR | 7 | 14 | 14 | 43 | 29 | | |
| I | 14 | 14 | | 14 | 14 | | |
| D | 5 | | | | 80 | | |

(Continued).

Table 5. Continued.

| Year and station[2] | No. of dives | Category[3] A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|
| <u>1980</u> | | | | | | | |
| NR | 7 | | | 14 | 43 | | 4 AL |
| SR | 7 | | | 14 | 14 | | 2 AL |
| I | 14 | | | | 14 | 7 | 2 AL, 1 YP |
| D | 3 | | | | | | |
| <u>1981</u> | | | | | | | |
| NR | 7 | 29 | | 43 | 71 | | 3 JD |
| SR | 7 | 29 | | 14 | 57 | | 32 AL, 2 YP |
| I | 14 | | | 7 | 7 | | 9 AL |
| D | 3 | | | 33 | 33 | | |
| <u>1982</u> | | | | | | | |
| NR | 2 | | 50 | | | | |
| SR | 2 | | 100 | | | 50 | 1 AL |
| I | 14 | | | | 7 | | |
| D | 2 | | | | | | |
| <u>All years</u> | | | | | | | |
| NR | 49 | 22 | 6 | 35 | 35 | | 14 AL, 3 JD, 1 SP |
| SR | 46 | 26 | 9 | 24 | 15 | 2 | 57 AL, 3 YP, 1 CC, 1 XX |
| I | 116 | 4 | <1 | 4 | 13 | 2 | 13 AL, 1 YP |
| D | 46 | 7 | 7 | 20 | 54 | 20 | 16 AL, 2 YP, 2 SS, 1 CP, 1 XX |
| <u>Total</u> | 257 | 14 | 4 | 16 | 25 | 5 | 100 AL, 6 YP, 3 JD, 2 SS, 1 CC, 1 CP, 1 SM, 1 SP, 2 XX |

1 Frequency of observation (%) = $\frac{No}{Nt} \times 100$
where: No = no. dives at station when observed,
Nt = total no. of yearly dives at station.

2 NR = north reference stations, SR = south reference stations, I = intake station, D = discharge station.

3 A = loose algae, B = dune grass, C = shreds or chips of wood, D = twigs and branches, E = trunks and stumps, F = fish (AL = alewife, CC = channel catfish, CP = common carp, JD = johnny darter, SM = rainbow smelt, SP = spottail shiner, SS = sculpin, YP = yellow perch, XX = unidentified fish).

grass, and shreds or chips of wood. At the intake and discharge stations, the uneven surface of riprap and abundance of interstices made observation of these small objects more difficult than at reference stations.

Tree stumps and trunks were observed infrequently (5% of total dives) and only once at a reference station. Stumps and trunks were most often observed at the discharge station. Their projections snagged on the uneven substrate. The solid foundation formed by the riprap also prevented the heavy stumps and trunks from sinking into the substrate. Water discharge currents from the Cook Plant kept these objects washed free of sediment that might otherwise have eventually covered them. On several occasions (1974-1976), divers observed tree trunks which were adjacent to the discharge structures and remained in place for several months, including winter.

In areas of sand substrate, moderately heavy objects resting on the bottom sank into the substrate and were rapidly covered by sediment. We observed many large chunks of wood, logs, and stumps during excavation of the lake bottom for placement of plant intake and discharge pipes. A portion of an excavated stump was examined and thought to have been buried along the shoreline during a previous low-level stage of the lake; possibly during the Chippewa (5,000-6,000 years ago) or Nipissing (4,000-5,000 years ago) stages (Hough 1958; personal communication, C. I. Smith, Department of Geology, University of Michigan).

Shells of snails and sphaeriid clams were observed occasionally, most often in troughs of large ripple marks or in shallow, flat-bottomed depressions in the riprap. These shells were often fragmented and many were severely eroded. This suggests that the shells were transported by waves and currents and accumulated in these areas of slack water. Divers often

encountered shells or fragments when sifting through coarse sand, but rarely when examining fine sand. Again, this was probably the result of the sorting of sediments by water movement; shell fragments contained in the fine sand were too small to be observed by the unaided eye.

Fish feces were commonly observed at reference stations. Alewife feces were most abundant during May-June when these fish concentrated in the area. Following commencement of heated water discharge from the plant during 1975, common carp began to be attracted to the area and feces of this fish were often found in abundance at reference stations closest to the discharge structures. The feces of these alewives and common carp undoubtedly increased the supply of organic material to detritivores and recycled nutrients to algae in the local area, but the significance of this contribution is unknown.

On a few occasions, dead crayfish were observed in the riprap zone but no pattern was detected in their occurrence. However, crayfish are often used by fishermen as bait for yellow perch that congregate over the riprap. Some of the dead crayfish seen by divers may have been discarded by these local fishermen.

Dead insect larvae and shells were observed occasionally but never in large numbers. Larvae of mayflies, water bugs, caddisflies, and water beetles were seen at both sand and riprap stations.

The preceding observations indicate that a spectrum of plant and animal material is available to detritivores inhabiting the inshore region of southeastern Lake Michigan. The role that detrital-feeding organisms play in lake ecology is discussed in more detail later in this report (see ECOLOGY).

Large accumulations of dead fish were never observed during dives in the vicinity of the Cook Plant (Table 6). The largest number of dead fish

Table 6. Record of dead fish observed during all dives in the vicinity of the D. C. Cook Nuclear Plant, southeastern Lake Michigan, 1973-1982. Blanks indicate no data.

| Date | Time | Water temp.(°C) Surface | Water temp.(°C) Bottom | Fish observed Species[1] | Fish observed Dead | Fish observed Live[2] |
|---|---|---|---|---|---|---|
| | | | North reference stations | | | |
| 25 Jun 75 | 1945 | 19.0 | 19.0 | AL | 1 | |
| 13 May 76 | 1333 | 13.0 | 12.0 | AL | 1 | |
| 9 Jun 76 | 1730 | 21.7 | 16.2 | AL | 1 | 75-100 |
| 19 May 77 | 1530 | 19.0 | 16.0 | AL | 4 | 1 |
| 13 Jul 77 | 1745 | 23.7 | 21.6 | SP | 1 | |
| 28 Jun 78 | 1515 | 20.5 | 16.5 | AL | 2 | |
| 25 Jun 79 | 1605 | 13.5 | 9.5 | AL | 2 | |
| 24 Jun 80 | 1605 | 19.0 | 17.4 | AL | 5 | |
| 26 May 81 | 1615 | 14.8 | 12.3 | JD | 3 | |
| | | | South reference stations | | | |
| 18 Jun 73 | 1717 | 22.0 | 18.0 | AL | 10 | 1 |
| 22 Jul 74 | 1945 | 15.6 | 10.0 | AL | 1 | |
| 23 Jul 74 | 1445 | 15.6 | 7.8 | AL | 4 | |
| 17 Jul 75 | 1450 | 25.0 | 22.8 | AL | 5 | |
| | | | | YP | 1 | |
| 15 Jul 76 | 1910 | 23.5 | 22.7 | AL | 1 | >1,000 |
| 19 May 77 | 1630 | 19.5 | 16.5 | AL | 2 | 25-30 |
| | | | | SM | 1 | |
| 28 Jun 78 | 1620 | 20.5 | 19.5 | CC | 1 | |
| 18 Jul 78 | 1556 | 18.0 | 15.0 | XX | 1 | |
| 28 May 80 | 1804 | 13.6 | 11.9 | AL | 2 | |
| 26 May 81 | 1635 | 14.5 | 12.5 | AL | 1 | |
| 23 Jun 81 | 1835 | 17.4 | 16.0 | AL | 30 | |
| | | | | YP | 1 | |
| 1 Jul 81 | 1630 | | | AL | 1 | 20 |
| | | | | YP | 1 | |
| 19 May 82 | 1722 | 19.0 | 17.0 | AL | 1 | >100 |
| | | | Intake station | | | |
| 16 Jul 75 | 1425 | 22.2 | 22.2 | AL | 1 | 1 |
| 8 Jun 76 | 2145 | 19.0 | 16.2 | AL | 1 | >1,000 |
| 15 Jul 76 | 1705 | 23.5 | 22.6 | SS | 1 | 2 |
| 28 May 80 | 1559 | 13.0 | 10.5 | AL | 2 | 1 |
| 28 Jul 80 | 0400 | 18.0 | 12.5 | YP | 1 | |
| 26 May 81 | 1720 | 15.5 | 12.0 | AL | 5 | 60 |
| 23 Jun 81 | 1900 | 18.0 | 16.5 | AL | 3 | 7 |
| 1 Jul 81 | 1730 | 18.0 | 13.0 | AL | 1 | 30 |

(Continued).

Table 6. Continued.

| Date | Time | Water temp.(°C) Surface | Bottom | Fish observed Species[1] | Dead | Live[2] |
|---|---|---|---|---|---|---|
| | | | Discharge station | | | |
| 16 Aug 73 | 1103 | 21.1 | 17.8 | YP | 1 | |
| 22 May 74 | 1150 | 12.0 | 11.0 | SS | 1 | |
| | | | | YP | 1 | |
| | | | | XX | 1 | |
| 12 May 76 | 1540 | 14.4 | 11.8 | AL | 11 | |
| 19 May 77 | 1330 | 19.6 | 15.4 | AL | 1 | |
| | | | | SS | 1 | 1 |
| | | | | CP | 2 | 18 |
| 16 Jun 77 | 1920 | 19.0 | 16.2 | AL | 8 | >100 |

1 AL = alewife, YP = yellow perch, SS = sculpin (*C. cognatus* or *C. bairdi*), JD = johnny darter, CC = channel catfish, CP = common carp, SM = rainbow smelt, SP = spottail shiner, XX = unidentified fish. See Appendix 3 for scientific names.

2 Number of live fish of same species observed during same dive.

observed during a single dive was 30 alewives, which were seen during a dive in June 1981 at a south reference station. Observation of more than 5 dead fish during a dive was rare, and of the 281 dives made in the vicinity of the Cook Plant during 1973-1982 (Table 1), dead fish were observed on only 35 occasions (12% of the dives).

During the 281 dives made near the Cook Plant, 125 dead fish were counted. Of this total, 107 or 86% of the fish were alewives (see Appendix 3 for scientific names); the remainder was comprised of yellow perch (5), slimy sculpin and johnny darter (3 each), common carp (2), spottail shiner (1), channel catfish (1), rainbow smelt (1), and 2 unidentified fish. All of these fish species were abundant in the study area (Tesar and Jude 1985) and were commonly observed by divers, with the exception of channel catfish.

No particular pattern or trend was detected in numbers of dead fish observed among stations or years. However, 71% of the dives during which dead fish were seen were conducted during May-June. This observation was not surprising because of the high percentage (86%) of dead fish that were alewives. Annual dieoffs of alewives have typically occurred during May-June in southeastern Lake Michigan since the late 1960s (Brown 1968, Jude et al. 1979). In fact, considering the thousands of dead fish occasionally seen floating on the surface of the lake above the divers and washed up directly onshore, the small number of carcasses seen on bottom was unexpected. An unquantified but probably small proportion of the alewife carcasses that sank to the bottom may have been eaten or decayed, but severely eroded or decayed fish were seldom seen. Most dead alewives seen inshore of the 10-m depth contour of the lake probably floated on the surface or bottom until they eventually washed up onshore. The continuous exposure of this inshore region

of the lake to waves and currents undoubtedly quickened the transport of dead fish to the beach.

Dead fish were never observed during April, September, and October. Inshore water temperatures were lower during these months than in May-August, and adult alewife and yellow perch remained farther offshore. The few dead yellow perch (5) observed during the underwater study were probably caught and discarded by local fishermen fishing from boats above the riprap and in-lake plant structures. Observations of all other species of dead fish were incidental and showed no pattern or particular significance.

Periphyton

Installation of the Cook Plant intake structures and associated riprap field was completed in late 1972. The surfaces of these objects then underwent a rapid sequence of initial rusting (of metallic surfaces), accumulation of sediment and organic detritus, and formation of bacterial slime. Much of this occurred in 1972-1973.

As the inshore water warmed during spring 1973, the surfaces of the structures and riprap began to be colonized by periphyton (attached algae), associated zooplankton, and other microscopic invertebrates. Macroscopic attached invertebrates such as sponges, bryozoans, and *Hydra* also appeared in small numbers on these surfaces.

The structures and riprap field were first examined by divers in June 1973. From 1973-1982, the length of periphyton on the top of the south intake structure and on riprap surrounding its base was measured by divers during most monthly dives (Appendix 1). Extensive colonization and growth of periphyton on the top of the intake structure occurred during its first year

in the lake because the periphyton was already 3.7 cm long when first examined in June 1973. Periphyton 0.5 cm in length also appeared on the upper surfaces of riprap surrounding the structure at this time. Periphyton grew rapidly on top of the structure during late spring and attained peak lengths during mid-summer. This was followed by sloughing of the algae during late summer and over-wintering at minimal lengths (Fig. 3). Although the pattern of growth for periphyton on top of the structure was similar for all years, peak length attained each year varied. This was primarily the result of mechanical abrasion by ropes tied to buoys surrounding the structure and diver-construction activities during some years. Periphyton attained greatest lengths on protected portions of the structure (e.g., crevices, flanges, etc.) and along the top edges of the structure.

Periphyton growth on riprap surrounding the base of the south intake structure followed an annual pattern that paralleled that on top of the structure. Peak lengths were usually less than those attained on top of the structure, except during years of abrasion to the top of the structure. The primary reason for reduced growth of periphyton on the riprap was the increased depth (an additional 3 m) and commensurate reduction in light.

Some basic patterns in periphyton growth on the structure or surrounding riprap were detected during the 10 seasons that the area was examined (Fig. 1). Periphyton growth was most luxuriant at the edges of the structure top and within 5 m of the base of the structure, probably the result of maximal water currents which occurred at these locations. The movement of water kept the periphyton free of sediment and increased exchange of gases and nutrients. Periphyton growth was limited on vertical surfaces and non-

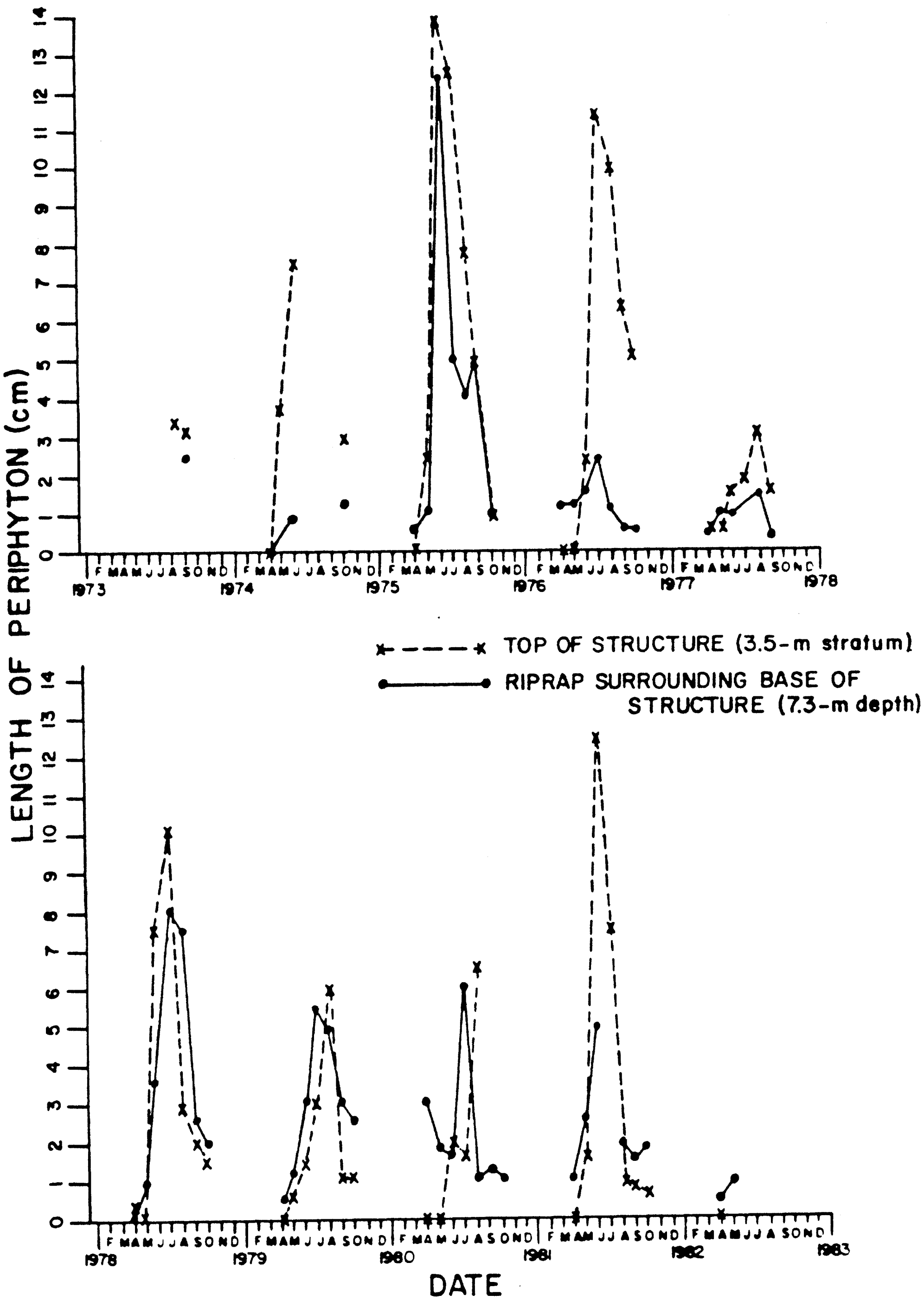


Fig. 3. Length of periphyton (mm) on top of the south intake structure (at the 3-m depth stratum) and on the upper surfaces of riprap (at the 7.4-m depth stratum) adjacent to the base of the structure. Measurements were made during dives in southeastern Lake Michigan near the D. C. Cook Nuclear Plant, 1973-1982.

existent on the undersides of the structure, riprap, and other unlighted surfaces at all depths.

The rapid attenuation of light with increasing depth also limited growth of periphytic algae. Periphyton growth at depths exceeding 10 m was minimal in comparison with that which occurred at lesser depths. A similar observation was made during our underwater examinations in 1978-1981 of fine-mesh screens, intake structures, and riprap at the J. H. Campbell Power Plant at Port Sheldon, Michigan, located 100 km north of the Cook Plant (Jude et al. 1982). Periphyton growth on all objects was depauperate in comparison with that observed on the upper surfaces of the Cook Plant structures and riprap. However, depths at the Cook Plant ranged from 4 to 9 m, while those at the Campbell Plant exceeded 10 m. At Hamilton Reef, located near Muskegon, Michigan, about 140 km north of the Cook Plant, periphyton was very sparse and *Cladophora* was absent (Cornelius 1984). The minimum depth of this reef is 8.3 m. Observations on the Campbell and Hamilton reefs suggest that periphyton growth is limited at depths greater than 7-8 m in eastern Lake Michigan.

These observations also suggest that, given the general light, temperature, and water transparency regime in southeastern Lake Michigan, clogging of water intake structures by periphytic algae should be limited to horizontal surfaces exposed to direct sunlight at depths less than 8 m. However, clogging of structures by attached invertebrates such as sponges, bryozoans, and *Hydra* would not necessarily be eliminated by increasing depth, and in fact these organisms became very dense on the Campbell Plant intake screens (Rutecki et al. 1985, Jude et al. 1982).

For several years prior to 1975, periphyton samples were collected from artificial substrates placed in the lake. Analysis of these samples provided

baseline information on the taxonomic composition of periphyton in the study area. Preliminary studies in 1974 and full sampling efforts occurred from 1975 through 1981. During this time, the sampling program was altered so that samples of periphyton were collected from the top of the south intake structure and surrounding riprap by divers. Comparison of the 1974-1981 diver-collected samples with those collected earlier from the artificial substrates revealed that direct sampling of periphyton from the structures and riprap to qualitatively assess colonization and growth of periphytic algae on these objects was preferable to use of hand-placed artificial substrates.

A distinct trend occurred toward increasing numbers of taxa, or taxonomic diversity, with time (Fig. 4; Table 7). Total numbers of taxa increased from 97 in 1975 to 189 in 1981. Numbers of previously unrecorded taxa followed a trend similar to that observed for total taxa but was less pronounced. This trend was mostly the result of an increasingly diverse diatom flora. The fraction diatom (Bacillariophyta) taxa made of total taxa increased every year (except 1980) from 58% in 1975 to 75% in 1981 (Table 8); data from 1974 were considered inconclusive because they were based on analysis of only one sample from June. The percentage of the total that green algae (Chlorophyta) comprised decreased by 14% during the same period. Percent composition of blue-green algae (Cyanophyta) remained relatively stable and varied from 4% in 1976 to 9% in 1978 (range = 5%). Other algae (Chrysophyta, Euglenophyta, Pyrrophyta, and Rhodophyta) comprised from 1% (1979) to 8% (1975) by number of the total taxa recorded for each year.

The increase in algal taxonomic diversity was accompanied by a decrease in numbers of dominant forms. In 1977, 8 of 97 taxa occurred in all samples; in 1978, 3 of 117 taxa were present in all samples; in 1979, no taxon was

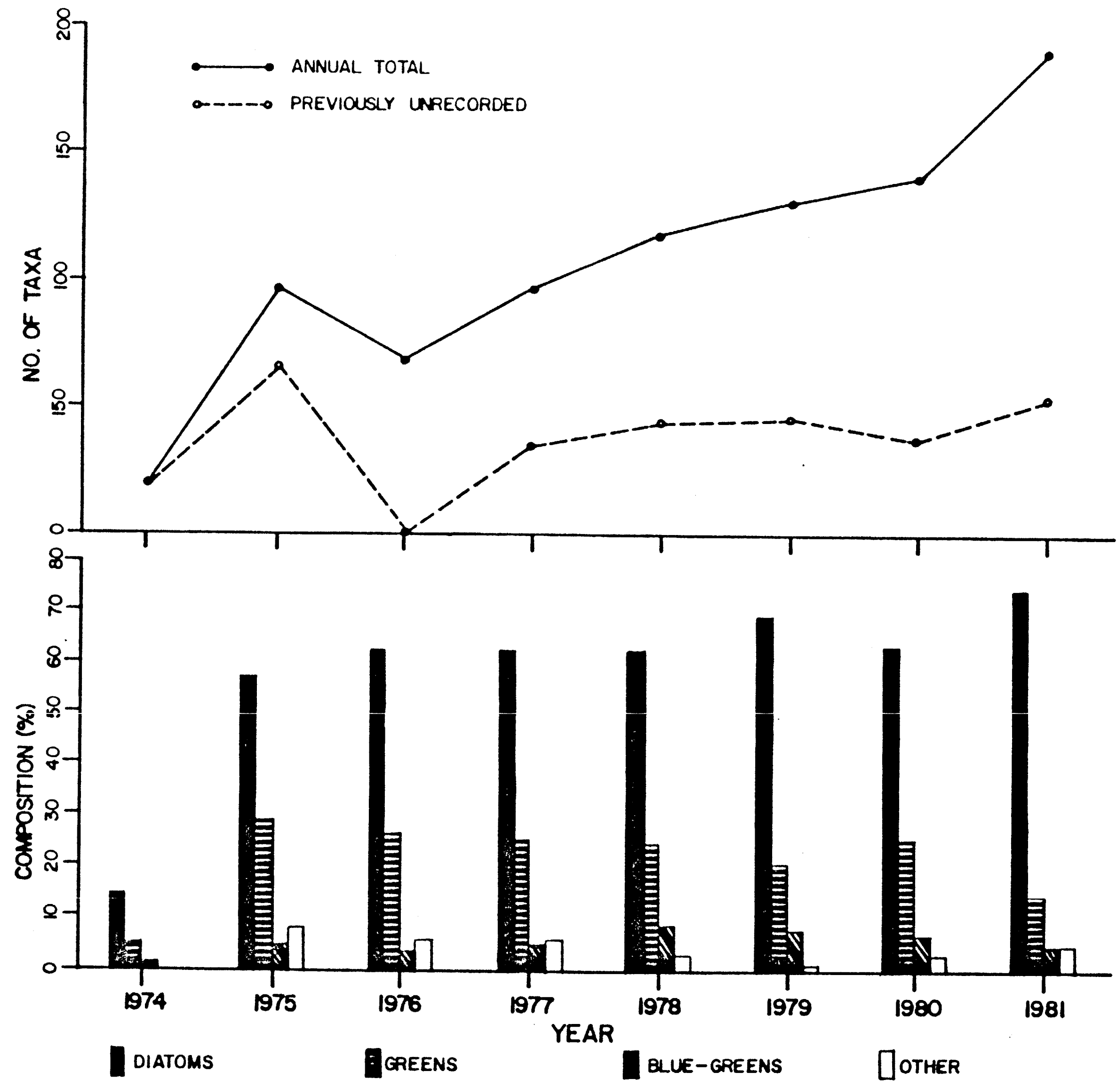


Fig. 4. Total number and percent composition by major groups of periphytic algae collected by divers from the top of the south intake structure of the D. C. Cook Nuclear Plant, located at the 3-m strata of the 9-m contour in southeastern Lake Michigan. One sample was collected each month, April-October, 1974-1981, in most years. A wet-mounted subsample was qualitatively analyzed under a microscope, and algae were identified to lowest recognizable taxon. Total number of samples analyzed each year was: 1974 = 1, 1975 = 5, 1976 = 6, 1977 = 4, 1978 = 7, 1979 = 7, 1980 = 7, 1981 = 7.

Table 7. Total number and number of previously unrecorded taxa of periphyton identified in diver-collected samples scraped from the top of the south intake structure of the D. C. Cook Nuclear Plant, 1974-1981. One sample per month, April-October, was collected each year with the exception of 1974 (all months but June omitted), 1975 (April and September omitted), 1976 (October omitted), and 1977 (April, May, and October omitted). Fraction (%) of total periphyton taxa that were also identified in samples of entrained phytoplankton collected from the plant forebay is also listed. Blanks indicate no samples collected.

| Year | No. of samples | Total no. of taxa | No. (%) taxa previously unrecorded | Percentage of taxa entrained |
|---|---|---|---|---|
| 1974 | 1 | 21 | 21 (100) | |
| 1975 | 5 | 97 | 66 (68) | |
| 1976 | 6 | 67 | 1 (1) | |
| 1977 | 4 | 97 | 34 (35) | 74 |
| 1978 | 7 | 117 | 43 (37) | 81 |
| 1979 | 7 | 131 | 45 (34) | 79 |
| 1980 | 7 | 141 | 38 (27) | 78 |
| 1981 | 7 | 189 | 54 (29) | 78 |

Table 8. Composition by number (and percent) of the number of taxa found in diver-collected periphyton samples scraped from the top of the D. C. Cook Nuclear Plant south intake structure during 1974-1981. One sample per month, April-October, was collected each year with the exception of 1974 (all months but June omitted), 1975 (April and September omitted), 1976 (October omitted), and 1977 (April, May, and October omitted). Algae were categorized as follows: diatoms = Bacillariophyta, green algae = Chlorophyta, blue-green algae = Cyanophyta, golden-brown algae = Chrysophyta, red algae = Rhodophyta, and other algae = Euglenophyta and Pyrrophyta.

| Year | Diatoms | Green algae | Blue-green algae | Golden-brown algae | Red algae | Other algae |
|---|---|---|---|---|---|---|
| 1974 | 15 (71) | 5 (24) | 1 (5) | 0 | 0 | 0 |
| 1975 | 56 (58) | 28 (29) | 5 (5) | 5 (5) | 1 (1) | 2 (2) |
| 1976 | 44 (63) | 19 (27) | 3 (4) | 3 (4) | 1 (2) | 0 |
| 1977 | 61 (63) | 25 (26) | 5 (5) | 2 (2) | 1 (1) | 3 (3) |
| 1978 | 75 (63) | 29 (25) | 10 (9) | 1 (1) | 0 | 2 (2) |
| 1979 | 101 (70) | 31 (21) | 11 (8) | 1 (1) | 0 | 0 |
| 1980 | 91 (64) | 37 (26) | 11 (7) | 1 (1) | 1 (1) | 1 (1) |
| 1981 | 142 (75) | 29 (15) | 9 (5) | 4 (2) | 0 | 5 (3) |

present in all samples; in 1980 and 1981, one taxon was present in all samples. During the period 1975-1980, the dominant green algae on the structure were species of Cladophora. During 1979-1981, length and density of Cladophora filaments growing on the structure were reduced relative to earlier years. Oscillatoria spp. were the dominant blue-green algae during all years expect 1981 when Anacystis incerta was most abundant. Diatoms of the genera Asterionella, Cymbella, Fragilaria, Melosira, Navicula, Nitzschia, Stephanodiscus, and Tabellaria were common in nearly all years. The golden-brown algae Dinobryon sp. was commonly recorded in samples, while red algae, flagellates, and euglenoids were occasionally noted.

Successive comparison of total numbers of taxa identified annually in the periphyton samples revealed: 54 taxa were present in 1981 only; 48 taxa were present in 2 of the 7 years; 23 taxa were present in 3 of the 7 years; 17 taxa were present in 4 of the 7 years; 10 taxa were present in 5 of the 7 years; 17 taxa were present in 6 of the 7 years; and 37 taxa were present in all years.

The fraction of periphyton taxa observed in samples of entrained phytoplankton collected from the Cook Plant forebay was consistently high, varying from 74% to 81% during 1977-1981 (Table 7). This observation suggests that considerable sloughing of periphyton occurs each year. Most likely, sloughing rates are highest during late summer and early fall as decreasing light levels and water temperatures result in die-off of much of the periphyton. Comparison between taxonomic lists of algae collected by divers and those collected in entrainment samples pumped from the plant forebay, suggests that entrainment sampling is an effective method for qualitatively assessing the diversity of periphyton attached to in-lake power plant structures during months when diving is not possible.

Several conclusions may be drawn from the observations presented in this section. Almost immediately upon their placement in the lake, underwater structures were colonized by periphyton, and considerable taxonomic diversity was achieved during the first year. However, there was a steady increase in the total number of taxa recorded each year, which was accompanied by a decline in number of dominant forms noted. A substantial number of rare taxa was recorded each year, and long-term dominant taxa were few in number. The largest number of previously unrecorded taxa was identified in 1981 samples, during the fifth and final year of the periphyton study. This suggests that ecological succession continued to occur 7 years after the structures and riprap had been placed in the lake, and that the taxonomic composition and relative abundance of periphyton had not yet stabilized at the end of this period. Evidence (Fig. 4) also indicated that periphytic succession would continue and that taxonomic stabilization was not imminent.

The decline in abundance of Cladophora during 1979-1981 was significant because, prior to that, these algae comprised most of the mass of periphyton seen and sampled from the area. Reasons for this decline are not known, but reduced abundance of Cladophora is related to declining phosphorus levels in Lake Michigan due to the phosphate ban in 1977 and reduced discharges at Chicago and Waukegan, Illinois. Presence (or absence) of Cladophora on substrates was shown to affect the distribution of some invertebrates (Lauritsen and White 1981).

## Attached Macroinvertebrates

Several taxa of invertebrates having one or more sessile stages during which they must attach to a substrate were observed by divers and included:

freshwater sponge, bryozoans, and *Hydra* spp. Observations of these animals were generally incidental relative to those of other invertebrates (snails and crayfish), but a few patterns emerged from the limited data (Appendix 1). Attached invertebrates were only observed on substrates in the riprap zone. Attached invertebrates were not observed in reference areas because of the absence of stable substrate.

Branched or multi-filamentous *Hydra* were first observed during September 1973 and were attached to riprap surrounding the intake structures. They were not observed again until 1978 when they were seen during standard series diving in October. *Hydra* were subsequently observed twice in 1979, and once in 1980 and 1982. These data are somewhat misleading in that they suggest the abundance of *Hydra* was low in the study area. When observed, *Hydra* occurred in tremendous numbers and often completely covered the upper surfaces of the riprap. During February 1977, a supplemental dive was made in the Cook Plant forebay where mats of *Hydra* 1-2 cm thick and more than 10 m in diameter were seen attached to the forebay walls. Commercial divers noted similar occurrences of *Hydra* during inspection of the interior walls of the plant intake and discharge pipes (personal communication, A. Sebrechts, Bridgman, Mich.). The abundance of *Hydra* on the intake structures and pipe explains its consistent occurrence in large numbers in entrainment samples.

In the open lake, *Hydra* were seen only during May and August-October, suggesting that conditions (e.g., water temperature, availability of specific planktonic prey) during June-July were not conducive to *Hydra* growth. Another possibility is that *Hydra* competed for substrate with algal periphyton which attained maximum growth during June-July. This hypothesis is consistent with

diver observations that *Hydra* were concentrated on the lateral and undersides of the riprap and plant structures where periphyton was absent.

The long-term distribution of *Hydra* showed a distinct pattern of initial colonization within one year of placement of substrates in the lake, followed by an extended period (1974-1977) of gradual expansion in distribution and density on these substrates. Peak abundance was achieved during 1978-1980, although *Hydra* continued to be observed throughout the duration of the study.

Bryozoans were observed during monthly dives once in 1974, three times in 1976, once in 1977, 1978, and 1980, and twice in 1981. Colonies were isolated and generally small, never exceeding a centimeter in diameter. No seasonal or temporal pattern in the abundance or distribution of this organism was detected during this study. Colonization of the structure and riprap by bryozoans occurred during the first two years that these substrates were in the lake.

Freshwater sponges were not observed in the study area until 1975, when they were seen during two monthly dives. Subsequently, they were seen during 3 mo in 1976, all months in 1977, 4 mo in 1978, 3 mo in 1979, 1 mo in 1980, 4 mo in 1981, and 1 mo in 1982. Both its seasonal and temporal distributions were more continuous than that of *Hydra* or bryozoans.

About two years were required for sponges to colonize the plant structures and riprap in sufficient numbers to be noticed by divers. It is possible that colonization of these substrates may have occurred more slowly than for *Hydra* or bryozoans, although this cannot be substantiated by our data. Numbers of sponge colonies appeared to stabilize during 1976-1978 and remained at similar levels of abundance through the remainder of the study.

Both the structures and riprap served as substrates for attachment of sponges, although they were observed most frequently on the riprap.

Sponges were not observed during dives in early spring (April-May) except in 1977. Generally, colonies were first observed during June, continued to increase in numbers throughout the summer, and remained abundant during the fall (September-October). In late summer, sponges were often bright green in color, a result of the inclusion of algal cells in the sponge matrix. Colonies usually appeared as flattened disks up to 1 cm in thickness and 10 cm in diameter, but occasionally formed finger-like outgrowths 2-3 cm in length. During late fall, sponge colonies became flattened and tan or white in color as the algal cells died, and a reduction or die-off of sponge was suspected to occur during the winter. Winter die-off and dormancy of most living cells contained in upper strata of the underlying skeletal matrix is typical of temperate freshwater sponges (Pennak 1953).

The general pattern of colonization of Cook Plant substrates by attached invertebrates was one of early appearance followed by slow expansion to available substrates. Riprap appeared to provide a more suitable substrate than did the metal structures, perhaps because rusting and sloughing of the metal surface occurred throughout the study, although the rate at which this process occurred declined in later years of the study. Peak abundance of attached macroinvertebrates occurred four to six years after placement of substrates in the lake. During the last several years of the study, the abundance of *Hydra* and bryozoans declined, while numbers of sponge colonies continued to fluctuate and showed no particular pattern or trend. Availability of substrate combined with moving (plant-circulated) water and presence of surficial sediment, organic detritus, and periphyton combined to provide a hospitable but

isolated micro-environment that was atypical of the surrounding inshore environment.

Underwater observations at both the Campbell Plant reef near Port Sheldon, Michigan (Jude et al. 1982) and Hamilton Reef near Muskegon, Michigan (Cornelius 1984) documented the colonization of riprap by sponges within one to two years of substrate placement in Lake Michigan. At the Campbell Plant, sponge colonies attached to wedge-wire intake screens in addition to the riprap, eventually necessitated cleaning of these screens. Farther north of the Campbell Plant at Hamilton Reef, sponges and unidentified fungi were common in diver-collected samples of invertebrates attached to the riprap (Cornelius 1984).

## Free-living Macroinvertebrates

Diver observation of unattached or free-living macroinvertebrates in the study area included aquatic stages of insect larvae, molluscs (clams and snails), and crustaceans (crayfish). These observations are summarized in Appendices 1-2.

Within and outside the riprap zone, divers observed larvae of Diptera (Chironomidae - true midges), Ephemeroptera (mayflies), and Trichoptera (caddisflies). Observations of these larvae were infrequent with no clear pattern. However, insect larvae were observed only during mid-spring (April-May) in the study area.

Other invertebrates observed in the area included the crustaceans *Mysis* (opossum shrimp) and *Pontoporeia* (scuds), and an adult of the insect family Notonectidae (back swimmers). *Pontoporeia* were observed only during late summer and fall (August-October) and never during spring or early summer.

Sightings of the above invertebrates were generally limited to the riprap zone. Often, these organisms were seen clinging to the sides or undersurfaces of stones. These animals were rarely seen in areas north or south of the plant. Most likely, invertebrates living in such areas of shifting sand substrate either buried themselves in the upper layers of the sediment and were not visible to the divers or were quickly eaten by fish.

Molluscs observed during the study included Sphaeriidae (fingernail clam) and Gastropoda (snails). Live sphaeriids were not observed because they were buried in the sediment. However, large numbers of empty shells were commonly seen at all stations. Sphaeriid shells accumulated in the troughs of ripple marks and in open depressions among the riprap. These accumulations were often several centimeters thick and several meters in length or diameter and attested to the abundance of these organisms in the study area. On one occasion one valve of a large pocketbook clam (Lampsilis ventricosa) was found at 6 m at the most northerly reference station (Fig. 2). Whether the specimen came from Lake Michigan or was transported from a connected inland lake was not known. However, we found lampsilid clams in abundance in the Grand Mere Lakes, a chain of shallow bar lakes located about 3 km north of the Cook Plant and which connect to Lake Michigan via an intermittent outlet.

Gastropods (snails) observed in the area during 1973-1982 included Physa, Goniobasis, and Lymnaea. Lymnaea were easily recognized by the high, sharp spire of their shell. Only shells of this snail were seen on a few occasions, and live specimens were never observed. Physa and Goniobasis were distinguished underwater by differences in the coil of their shell (sinistral and dextral, respectively). Laboratory identification of snails collected over a period of several years revealed that most specimens were Physa integra

and documented this snail to be the predominant gastropod inhabiting the Cook Plant riprap.

Gastropod speciation at the J. H. Campbell Plant differed considerably from that observed for the Cook Plant. The Campbell Plant riprap was initially colonized by Valvata which were later displaced by Lymnaea, and Physa were never observed at the Campbell Plant (Rutecki et al. 1985). Interestingly, Valvata were seen in great abundance during a pre-construction underwater survey of the site in 1977 (Jude et al. 1978) and were the most abundant gastropod in Ponar grab samples of sediment collected during 1977-1979 from areas north and south of the plant (Winnell and Jude 1981).

The difference in species distribution of gastropods between the Cook and Campbell reefs was probably related to differences in physical and biological conditions at the two reefs. The increased size of the riprap and interstitial spaces, combined with greater depth and subsequently reduced storm-generated water turbulence, less periphyton, and absence of Cladophora on the Campbell Plant reef, may have favored or excluded certain species of snails. Pennak (1953) noted that Physa occurs in greatest abundance where there is a moderate amount of aquatic vegetation but is rare in areas where there are dense mats of vegetation. This may, in part, explain why Physa initially colonized the Cook riprap but disappeared in later years as periphyton became more abundant on the reef. Absence of periphyton or other vegetation on the Campbell riprap may have discouraged colonization of this reef by Physa. On the other hand, Lymnaea is found in a wide variety of habitats (Pennak 1953). This snail was abundant on the Campbell reef and its shells were occasionally collected at the Cook reef. No exact explanation could be made for the presence of Valvata on the Campbell reef and its absence

on the Cook reef. However, there is a major anatomical and physiological difference in the respiratory mechanism of the Valvatidae when compared with the Physidae and Lymnaeidae. The Valvatidae have external plumose gills; whereas, the Physidae and Lymnaeidae have a "lung" or pulmonary cavity. Also, most pulmonate snails come to the surface to breathe (although a large number do not) and therefore generally tend to inhabitat shallow water. The increased depth of the Campbell reef along with absence of periphyton that might interfere with external gills may have favored the valvatid snails.

Numbers of snails (primarily *Physa*) at the Cook Plant did not show any strong pattern of seasonal abundance during April-October, except that they tended to be most abundant during April-June and August-October and were never abundant during July (Fig. 5). However, a clear pattern of temporal abundance emerged during the study. Snails were observed in large numbers during 1973-1975 and peaked in abundance during May 1975 when 30-100 snails/$m^2$ were counted during dives at the south intake station. These numbers include only snails immediately visible to divers without disturbing the riprap. In actuality, the density of snails was probably several times greater than 30-100/$m^2$, because they were abundant on the sides and undersurfaces of the riprap as well as on stones beneath the surficial layer of riprap. Following 1975, a precipitous decline in snail abundance occurred during 1976-1978. No snails were observed in the study area from 1979 through 1982.

The riprap was colonized by snails during its first year in the lake and supported large populations of *Physa* for about three years. At that point, habitat conditions or some other ecological effect occurred that rendered the riprap unsuitable for *Physa*. As previously noted, it is possible that after several years, the accumulation of sediment and periphyton on the surface of

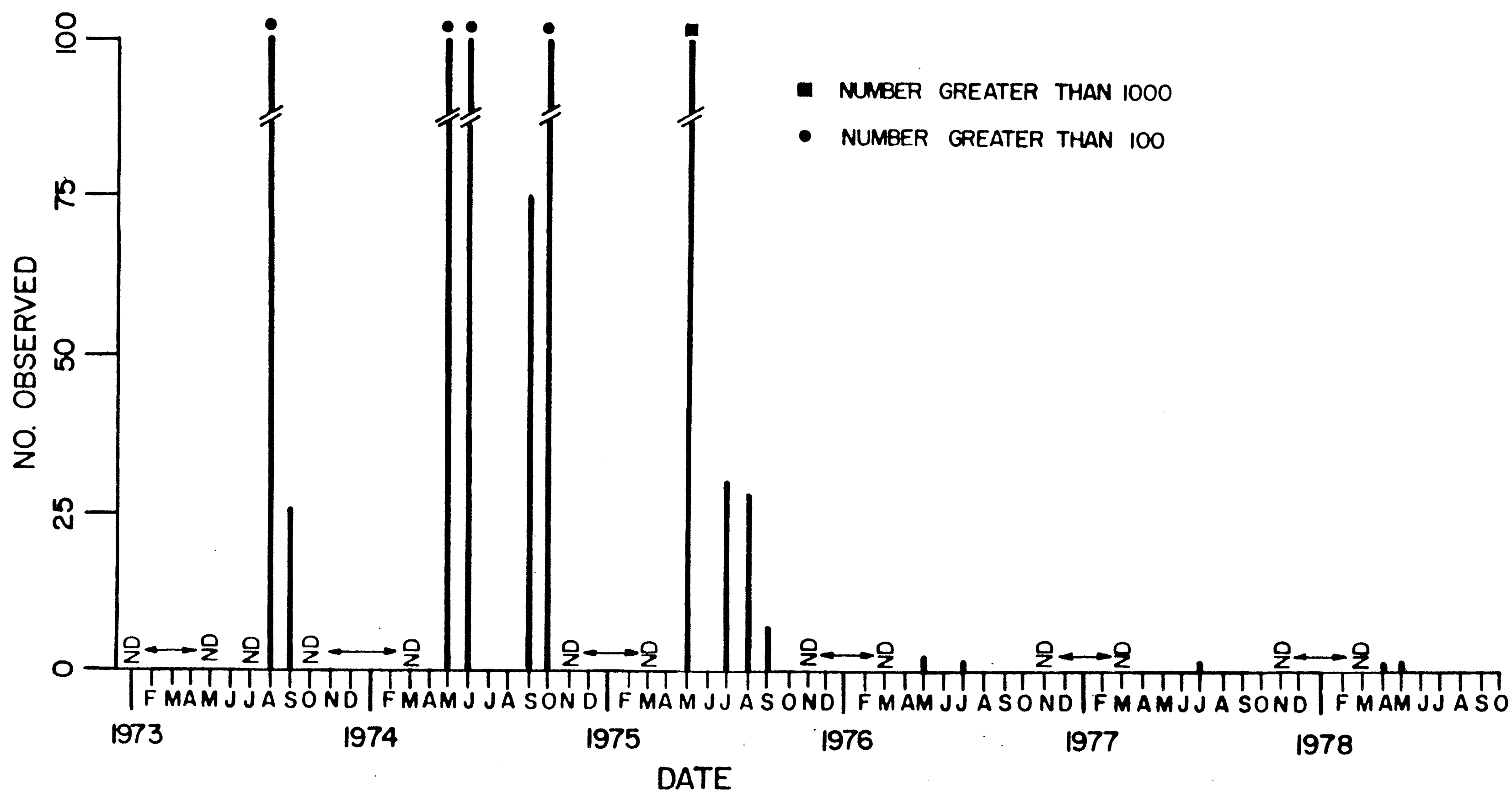


Fig. 5. Numbers of snails observed by divers in southeastern Lake Michigan near the D. C. Cook Nuclear Plant, 1973-1982. Snails were seen only at stations within the riprap zone and none was observed after 1978. ND = no diving that month.

the riprap reached a point at which it interfered with the respiration or movement of the snails. Another possibility is that composition of microscopic flora and fauna that snails fed upon was altered through the accumulation of sediment and periphyton, and eventually the riprap surfaces no longer provided suitable food for the snails. Yet another possibility is based on the observation that snail egg cases were commonly observed during the first few years of diving but not in later years. Perhaps as the surface of the riprap aged and accumulated material, it was no longer sufficiently clean to serve as substrate for the attachment and incubation of these eggs.

On a few occasions, live snails were seen on the metal surfaces of the intake and discharge structures. However, only isolated animals were observed and densities never exceeded one snail per several square meters. The surface of the structures was always covered with either periphyton and sediment, or, when periphyton was absent, rust. The snails may have avoided all such surfaces. Also, snails were quite obvious on the flat surface of the structure and may have been more susceptible to predation by fish.

In contrast to sightings of Valvata in areas surrounding the Campbell reef, live snails were never observed by divers in sand-substrate areas surrounding the Cook Plant riprap zone. No explanation can be offered for this difference. However, snails were observed in areas of natural (clay, cobble) rough substrate north and south of the Cook Plant (Dorr 1982). These isolated areas of naturally occurring, stable substrate probably served as preserves on the lake bottom where snails, along with crayfish and attached invertebrates could survive and emigrate to areas of newly placed artificial substrate.

Information on the abundance and distribution of decapods (crayfish) in the study area originated from two sources: diving observations made during 1973-1982 and records of their impingement from 1975 through 1981 on Cook Plant traveling screens (Fig. 6). Three species of crayfish were present in impingement samples; Orconectes propinquus, O. virilis, and Cambarus diogenes diogenes. Only isolated specimens of the latter two species were collected, representing only a fraction of a percent (0.08%) of all crayfish collected (Winnell 1984). Crayfish were observed during all years of the underwater study, although their abundance fluctuated during this period. It was assumed that most crayfish observed by divers were O. propinquus, based on the predominance of that species in impingement samples.

Crayfish were observed more frequently at night than during the day (Fig. 7). This was in accordance with the generally nocturnal habits of this animal which remains hidden in burrows or under substrate during the daytime (Pennak 1953). At the Cook Plant, crayfish could be found during daytime by excavating some of the riprap. At night, crayfish emerged and rested on top of the stones or among the interstices.

Comparison of total numbers of crayfish observed by divers each month with numbers of crayfish impinged documented a general pattern of initial low abundance, followed by rapid population growth, and then by a decline to about one-tenth of peak abundance. Crayfish were observed in 1973 and had therefore colonized the reef within one year of its placement in the lake. During 1979-1982, numbers of crayfish observed and impinged fluctuated but remained within the same general upper and lower limits during the period.

During April-October, 1975-1982, day and night observations were made at two side-by-side, 1 x 10 m transects adjacent to the base of the south intake

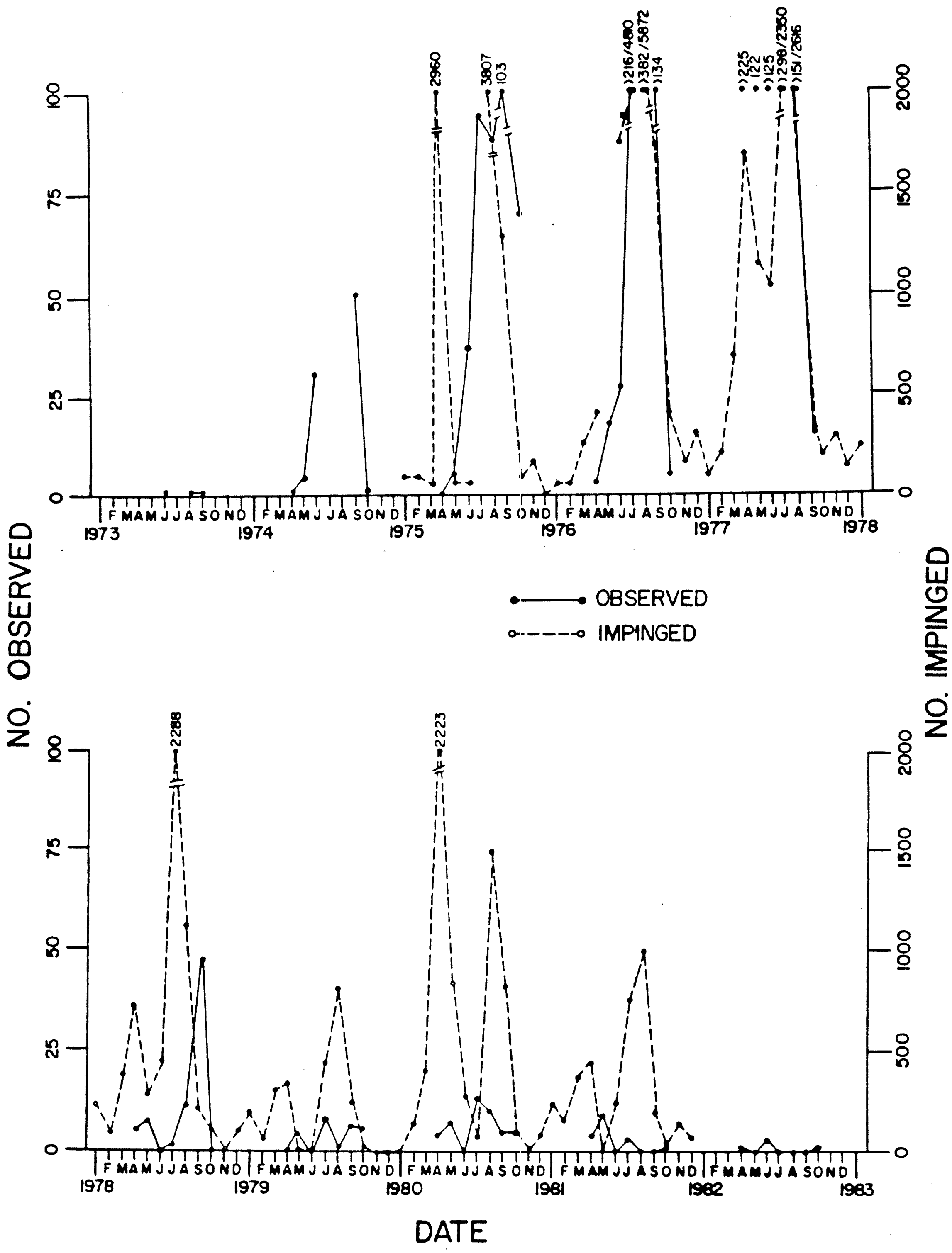


Fig. 6. Numbers of crayfish observed by divers (1973-1982) and impinged on traveling screens (1975-1981) at the D. C. Cook Nuclear Plant, 1975-1981, southeastern Lake Michigan.

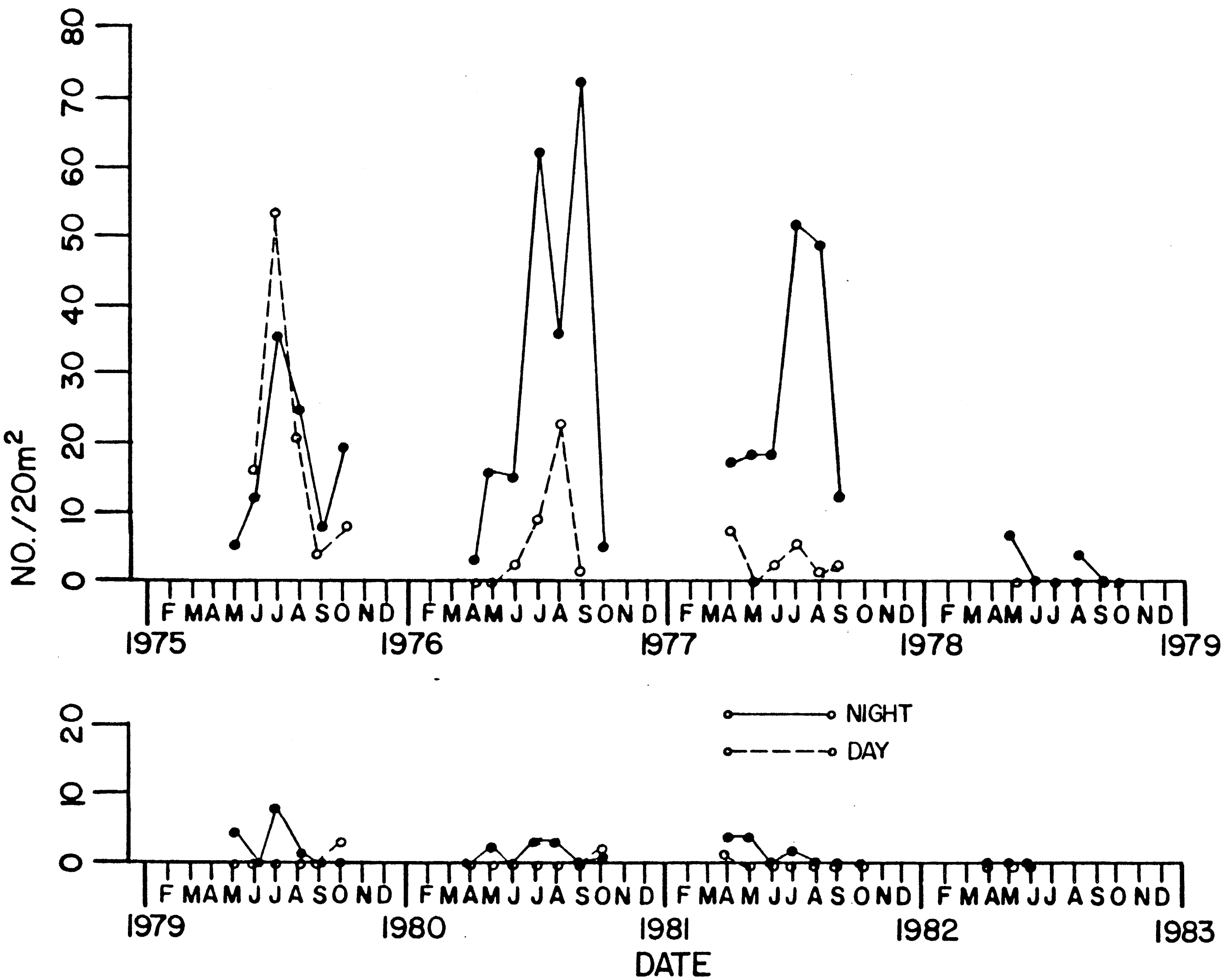


Fig. 7. Total numbers of crayfish seen by divers during day and night swims over two adjacent 1 x 10 m transects (20 $m^2$ total area) along the base of the south intake structure of the D. C. Cook Nuclear Plant, southeastern Lake Michigan, 1975-1982.

structure. These observations were pooled to yield numbers of crayfish (and other organisms) observed per 20 $m^2$. These quantified observations were based on standardized methodology and constituted the most reliable database from which conclusions could be drawn based on underwater observations. Comparison of transect observations of crayfish (Fig. 7) with total numbers of crayfish observed and impinged in the study area (Fig. 6) revealed a corroborating pattern of temporal abundance. As with total numbers of crayfish observed and impinged, peak abundance of crayfish recorded during transect observations (72/20 $m^2$) also occurred during 1976, although more were seen during September than August. Transect observations also support the conclusion that crayfish were most abundant on the Cook Plant riprap during 1975-1977 and that their abundance declined precipitously during 1978. They continued to be observed in small numbers through 1981 but none was seen in 1982.

The reason for the abrupt decline in abundance of crayfish in 1978 is unknown. Peak numbers of crayfish impinged during 1978 approached 1977 levels but sustained impingement during 1978 was clearly less than that of 1977. Total and transect observations of crayfish declined by a factor of 10 during the period 1977-1978. It appears that some environmental factor or ecological relationship changed during the period fall 1977-spring 1978 and caused a rapid decline in abundance of crayfish on the Cook Plant riprap. A similar decline in abundance of snails was discussed earlier, although it occurred during 1976, about two years in advance of the crayfish population decline.

Peak abundance of crayfish recorded during transect observations (September 1976 - Fig. 7) was 72/20 $m^2$ or about 4/$m^2$. However, this number included only those animals visible to the divers who did not displace the riprap during transect swims. Based on non-transect observations during which

the riprip was overturned, it is possible that actual abundance of crayfish may have peaked at 8-10/$m^2$. Based on numbers and weights of crayfish impinged during the same month, the average weight of these crayfish was 5.1 g. This extrapolates to an observed abundance of 20.4 g/$m^2$ (162 lbs/acre) and an estimated abundance of 41-51 g/$m^2$ (364-445 lbs/acre). Pennak (1953) noted that pond populations of crayfish generally do not exceed 100 lbs/acre but in exceptional cases may attain 500-1,500 lbs/acre. These data suggest that at peak abundance, the riprap supported a relatively dense population of crayfish. It is possible that within two to three years the carrying capacity of the habitat may have been exceeded which resulted in the subsequent decline in crayfish abundance observed during later years of the study.

Unlike the Cook Plant reef, no crayfish were observed during four years of diving (1978-1981) on the Campbell Plant reef. Rutecki et al. (1985) attributed this disparity to differences in reef composition and configuration. Surficial riprap surrounding the Cook Plant intakes was composed of stone ranging from about 0.1-0.6 m in diameter and weighing about 1-50 kg. Campbell Plant riprap was considerably larger than Cook Plant riprap, usually exceeding 1 m in diameter and weighing 225-900 kg. The interstices among the Campbell riprap were much larger than those of the Cook Plant and may have provided crayfish with less protection from fish predation (e.g., slimy sculpin, yellow perch), especially during the egg and juvenile stages.

Another possible explanation for the absence of crayfish on the Campbell reef is that, in contrast to the Cook riprap, periphyton was extremely depauperate on the Campbell riprap and Cladophora was absent. Prince et al. (1975) found that in Smith Mountain Lake, crayfish were abundant in areas

supporting luxuriant *Cladophora* and absent from areas with little or no growth of this alga. Crayfish are omnivorous and are known to eat aquatic vegetation (Pennak 1953). It is possible that *Cladophora* constituted an important component of the diet of crayfish at the Cook Plant and that absence of this or other aquatic vegetation on the Campbell riprap resulted in an inadequate supply of food. Lauritsen and White (1981) found that the seasonal abundance of some predacious and filter-feeding zoobenthos was correlated with the the luxuriance of *Cladophora* on the Cook Plant riprap. These zoobenthos may have served as prey for crayfish, thus providing a trophic link through which the abundance of *Cladophora* could affect the abundance of crayfish on the reef.

These observations correspond with those of Cornelius (1984) for Hamilton Reef near Muskegon, Michigan. This artificial reef is similar in composition and location to the Campbell reef, although its configuration is somewhat different in that the riprap is separated into numerous piles several meters apart which are interspersed by areas of sand. Like the Campbell reef, periphyton was scarce on the Muskegon reef, *Cladophora* was absent, and crayfish were not observed during three field seasons of diving. Elsewhere in the area, Dorr (1982) documented the presence of crayfish in areas of naturally occurring cobble substrate located near Saugatuck and South Haven, Mich., between the Campbell and Cook Plants. These substrates also supported periphyton, although growths were never as luxuriant as those seen at the Cook Plant. However, abundance of crayfish was also lower at these locations than at the Cook Plant. The above observations argue for the existence of a relationship between abundance of periphyton, *Cladophora* in particular, and that of crayfish on inshore reefs in eastern Lake Michigan.

During 10 years of diving at the Cook Plant, only one crayfish was seen in an area of sand substrate outside the riprap zone. This attests to the critical role that substrate plays as a limiting factor in the life history and distribution of crayfish, particularly in such a harsh environment as occurs inshore in eastern Lake Michigan.

## Fish Spawning

Spawning by numerous species of fish has been inferred from catches of male and female fish with ripe-running gonads in the inshore region of Lake Michigan near the Cook Plant (Jude et al. 1979, Tesar et al. 1985). Occurrence of newly hatched yolk-sac larvae in plankton net hauls in the lake and entrainment samples collected from the plant forebay (Bimber et al. 1984, Noguchi et al. 1985) supports this inference. More direct evidence of fish spawning in the immediate vicinity of the Cook Plant was provided by *in situ* observation of eggs of five fish species: alewife, spottail shiner, yellow perch, johnny darter, and slimy sculpin.

Fish eggs were observed during all years of the study except 1982 (Appendix 1). Eggs were observed exclusively during May-August (Fig. 8). Duration of occurrence for a given species ranged from about 3 weeks for yellow perch and sculpin to about 10 weeks for alewife.

The line graphs in Figure 8 must be interpreted with care because they present information on different components of the reproductive cycle. The basic progression of events during reproduction should be the appearance of ripe-running fish in the area followed (or paralleled) by spawning and deposition of eggs. Next would come a period of egg incubation during which

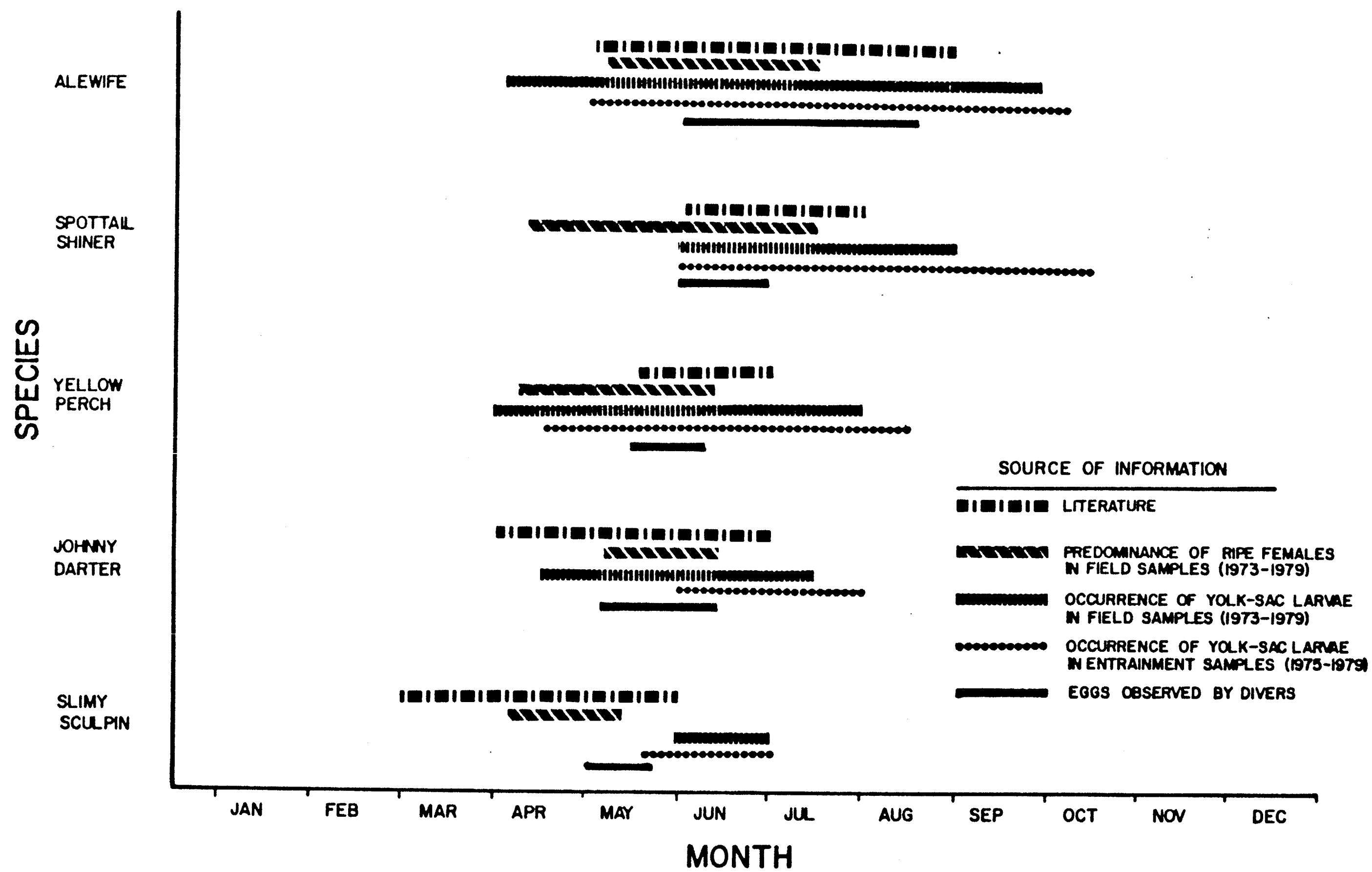


Fig. 8. Chronology of maturation, spawning, egg incubation, and hatching of alewife, spottail shiner, yellow perch, johnny darter, and slimy sculpin, in southeastern Lake Michigan near the D. C. Cook Nuclear Plant. Spawning periods were cited from Auer (1982); all other data were compiled during 1973-1982 studies at the Cook Plant.

eggs might be observed *in situ* followed by hatching and appearance of yolk-sac larvae in the area.

Most data presented in Figure 8 were compiled exclusively from diving observations and concurrent studies of adult and larval fish at the Cook Plant, with the exception of the literature survey. Therefore, some disparity between reported spawning periods and the timing of other events in the reproductive cycle shown in Fig 8. was expected. This occurred because the literature survey included habitats other than the Cook Plant where environmental conditions might elicit spawning at other times of the year. For example, temperature-dependent spawning of fish may occur earlier in the year in a shallow inland lake where the water warms more rapidly in spring than in Lake Michigan.

Another cause for the disparity among events depicted in Figure 8 may be that these data summarize the findings from several years of study. Some variability occurred among years in the timing of reproductive events (e.g., maturation of gonads, deposition of eggs, and hatching of larvae). Therefore, for any given year, the duration of reproductive events was probably shorter than the periods shown.

Alewife showed the most protracted period of reproductive activity among the five species. Over a 4-6-yr period, yolk-sac larvae were taken in field samples as early as April and appeared in both field and entrainment samples until the beginning of October. Occurrence of ripe adults (early May-mid-July) and observation of eggs (June-mid-August) were in close agreement in terms of the sequence of these reproductive events. The spawning period reported in the literature for alewife was longer than that suggested by adult fish studies and diving observations but agreed with the occurrence of yolk-

sac larvae late in the summer. The appearance of yolk-sac larvae in field and entrainment samples during April was difficult to explain in terms of the data presented in Figure 8 but may have resulted from exceptionally early spawning by a few fish. Yolk-sac larvae were never captured in large numbers during April or early May. The period from mid-May through July appeared to encompass the bulk of alewife spawning and egg incubation in the study area. Most eggs observed during late July and August were either opaque or fungused, indicating that they were no longer viable.

Of these five fish, alewife, spottail shiner, yellow perch, johnny darter, and slimy sculpin, only alewife has pelagic eggs that are randomly broadcast during spawning; the other four species have demersal eggs that adhere to the substrate. Also, only alewife eggs were observed in areas outside the riprap zone. The eggs often accumulated and formed a thin layer in the troughs of the ripple marks at the sand-substrate reference stations north and south of the plant. Alewife eggs were commonly observed on top of the riprap and plant structures, trapped among the filaments of periphyton. Eggs were seen in about equal abundance in the riprap zone and at reference stations. No indication of area- or substrate-selective spawning was noted.

During 1973-1982 adult fish studies near the D. C. Cook Nuclear Plant, several thousand yellow perch stomachs were examined. Many were found to contain alewife eggs, thereby documenting predation by yellow perch on these eggs (unpublished data, Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich.). These studies and those of Dorr (1982) showed extensive yellow perch predation on young-of-the-year and adult alewife as well. Yellow perch predation on large larval alewives was suspected, but larvae were not found in the stomachs of yellow perch, probably because of the rapid rate at which this material was

digested beyond recognition. The Cook Plant adult fish studies also documented a dramatic increase in abundance of yellow perch in the area and a concurrent decline in abundance of alewife (Tesar and Jude 1985, Jude and Tesar 1985). The recent decline in abundance of alewife in Lake Michigan probably resulted from salmonine predation. Increased abundance and predation of yellow perch on eggs, larvae, juveniles, and adult alewife combined with that from stocked salmonids may cause a possible future collapse of alewife stocks in Lake Michigan.

Spottail shiners were observed spawning on top of the south intake structure during a night dive in 1973. As the eggs were broadcast over the mat of periphyton that covered the surface of the structure, they settled into the periphyton and adhered to the algal filaments. Spawning was not observed on the riprap. On several occasions during later years, a few eggs were collected from the top of the structure and incubated in the laboratory, and the newly hatched larvae were identified as spottail shiners.

The chronology of reproductive events observed for spottail shiners in the study area (Fig. 8) closely paralleled the expected timing of events. Ripe fish were caught during mid-April-mid-July. Spawning and eggs were observed during June. Yolk-sac larvae appeared in field samples from June through mid-August and in entrainment samples from June through mid-October. The bulk of spottail shiner spawning, egg incubation, and hatching occurred during June-mid-July in the study area. The only unexplained component of the data (Fig. 8) was the observation of yolk-sac larvae in entrainment samples during September and October, one to two months after ripe fish ceased to be collected in the area. The spawning period reported in the literature for

spottail shiners was in close agreement with that which would have been predicted from field study data.

Spottail shiner eggs were occasionally seen on the riprap but never at reference stations. This is probably due to the more nearshore distribution ($\leq$3 m) of their eggs.

Maturation, spawning, egg incubation, and hatching of yellow perch in the study area was examined in detail by Dorr (1982). He documented that spawning and incubation of yellow perch eggs was limited to areas of rough (natural or artificial) substrate. Yellow perch egg masses were never observed on sand substrate during nearly 500 dives in the study area which encompassed 10 spawning seasons (Dorr and Jude 1980a,b; Dorr 1982). These findings concur with those reported in the literature and clearly establish that in southeastern Lake Michigan yellow perch spawned selectively on stable, rugose substrate. These substrates probably serve to anchor the eggs and suspend them slightly above bottom, thereby reducing settling of eggs into the substrate or transport to areas with conditions less favorable to survival, e.g., the turbulent beach zone.

In addition to the Cook Plant reef, evidence of yellow perch spawning on two other artificial reefs in eastern Lake Michigan has been compiled. Although yellow perch egg masses were never observed on the Campbell Plant reef (Rutecki et al. 1985), the high abundance of ripe fish and yolk-sac larvae in field samples and predominance of yellow perch larvae in entrainment samples (Jude et al. 1982) suggest that perch spawned on this reef. Yellow perch eggs were usually observed _in situ_ for no more than 2 weeks (Dorr 1982); most likely, the timing and intensity of diving on the Campbell reef was inadequate to

permit observation of eggs. Biener (1982) reported aggregation and spawning of yellow perch on Hamilton Reef near Muskegon, Michigan, in 1981.

Yellow perch egg masses were also observed in areas of natural rough substrate by Dorr (1982). Masses were seen at 6-9 m on cobble substrate near Saugatuck and South Haven, Michigan, and on rugose clay substrate 3 km north of the Cook Plant and on New Buffalo shoals south of the plant. Egg masses have also been seen on clay substrate near Michigan City, Indiana (personal communication, G. McDonald, Ball State Univ., Muncie, Indiana).

Capture of ripe yellow perch during early April-early June and observation of eggs during mid-May-early June corresponded with the expected timing of these events. Occurrence of yolk-sac larvae in field and entrainment samples during mid-May-July corresponded with maturation and spawning. The occurrence of yolk-sac larvae in the study area during April and early May has been attributed to riverine input of larvae spawned in inland waters that warm to spawning temperatures earlier in the spring than inshore Lake Michigan waters (Wells 1973; Jude et al. 1979, 1981a; Dorr 1982; Perrone et al. 1983). Appearance of yolk-sac larvae in August entrainment samples may have been the result of some isolated late spawning or unusually slow maturation of larvae.

The spawning period (mid-May to mid-June) reported for yellow perch in southern Lake Michigan corresponded closely with that predicted from Cook Plant fish and underwater studies. Lake Michigan yellow perch have a short reproductive season relative to other fish species, and the bulk of spawning, incubation, and hatching occurs during a 3-4-week period from mid-May through early June in this area of the lake.

Johnny darter eggs were found on two occasions in 1977, during May and June. In May, one cluster of eggs was found attached to the underside of a

fiberglass washtub and another was attached to the underside of a swim fin. Both of these objects had been lost from the dive boat during the previous month. In June, two more clusters of eggs were found attached to the underside of a flat slab of wood. The female darter often lays her eggs in several clusters each containing 20-200 eggs (Scott and Crossman 1973); the two clusters of eggs found on the wood slab may have been spawned by a single fish. The clusters were 2-3 cm in diameter and were composed of several hundred eggs packed closely together in a single layer. The eggs were collected, hatched in the laboratory, and larvae verified as johnny darters.

The concurrent appearance of ripe fish in field samples and observation of eggs during mid-May to mid-June (Fig. 8) defined a short spawning period for johnny darters in the study area. The occurrence of yolk-sac larvae in field and entrainment samples during mid-May-July was in general accord with the timing of spawning and incubation of eggs, as was the spawning period reported in the literature. But, like the other species, both early and late occurrences of yolk-sac larvae were noted. These data suggest that the bulk of johnny darter spawning, incubation, and hatching occurs from mid-May through late June in the study area.

Sculpin eggs were found on two occasions, in May of 1974 and 1978. In both instances, the eggs occurred as a flattened mass attached on the underside of a piece of riprap. These masses were similar in appearance to the johnny darter egg clusters except that both the individual sculpin eggs and size of the egg mass were larger than those of the darter. On both occasions, the collected eggs were incubated in the laboratory until the larvae hatched and were identified as slimy sculpin (*Cottus cognatus*).

The chronology of reproductive events documented for slimy sculpin by Cook Plant fish and diving studies was nearly perfect, in biological terms. Ripe adults were caught during April-mid-May, and eggs were observed during the first three weeks of May. Yolk-sac larvae appeared in entrainment samples from mid-May through June and in field samples during June. Larvae appeared in entrainment samples about two weeks earlier than in field samples, because sculpin spawning was concentrated in the riprap zone where field net tows were not conducted. Netting was conducted north and south of the riprap, and some time probably elapsed before the newly hatched larvae migrated from their nests in the riprap zone to surrounding areas of the lake where they were subsequently netted. The spawning period reported in the literature generally agreed with that predicted from Cook Plant data. Again, spawning reported during March-early April probably occurred in inland waters that warm to spawning temperatures more rapidly than inshore Lake Michigan. These data (Fig. 8) indicate spawning, egg incubation, and hatching of sculpins occurs during a relative brief period, with the bulk of this activity taking place during late April-late May.

Several conclusions may be drawn from the preceding discussion on reproductive activity of fish in the study area. Two general modes of spawning were noted: fish that broadcast their eggs at random without regard to substrate type and fish with substrate-specific spawning requirements. Alewife was a primary example of the first category of spawner. Its eggs were pelagic and ubiquitously distributed. Examples of the other spawning mode included spottail shiner, yellow perch, johnny darter, and slimy sculpin. Spottail shiner eggs were demersal and adhesive and were found attached to a variety of stable substrates. It appeared that while this species selects

stable substrates for spawning, the composition and configuration of that substrate is not a critical factor in the selection process. Johnny darter and slimy sculpin were more selective in that eggs were laid on the flat, clean undersides of riprap and inorganic or organic debris. As in other studies in the area (Biener 1982, Dorr 1982, Rutecki et al. 1985), yellow perch were found to have rather specific substrate requirements that focused on substrate configuration and rugosity. Finally, related studies (Dorr and Jude 1981a, Dorr et al. 1981b, Jude et al. 1981b) in the area have compiled evidence that some species such as lake trout have extremely specific spawning-substrate requirements that include characteristics such as composition, configuration, rugosity, and interstitial dimensions.

With the exception of alewife and spottail shiner, spawning was concentrated in the riprap zone, and much of the reproduction of the species discussed occurred during May-June. During this period, survival and growth of these fish populations could be affected by perturbations of specific events (spawning, incubation, hatching and early survival) in their reproductive cycle. Populations of pelagic spawners such as alewife that broadcast their eggs randomly over a wide area are less likely to be affected by a point ecological impact than populations of fish which concentrate their spawning in the area of the impact. With regard to johnny darters, slimy sculpins, and to a small degree spottail shiners, an ecological trade-off exists between reproduction and plant operation. These species concentrate around and spawn on in-lake plant structures, thus increasing their vulnerability to impingement, entrainment, and physical (heat) and chemical (chlorine) discharges. But at the same time, populations of these fish have

been enhanced by the creation of this artificial substrate and would not exist in such abundance if the plant structure were not present.

Juvenile and Adult Fish

Twenty-two taxa encompassing 24 species of fish were observed by divers during the study and were grouped according to frequency of observation (Table 9) from data presented in Appendix 1. Frequently observed species included alewife, yellow perch, sculpins (slimy sculpin and mottled sculpin), johnny darter, and spottail shiner. All of these fish were seen at least once during each year of the study. Commonly observed species included trout-perch, common carp, rainbow smelt, burbot, and white sucker. These fish were seen during seven to nine years of the study. Uncommonly observed species included largemouth bass, lake trout, channel catfish, black bullhead, smallmouth bass, and longnose sucker. These fish were seen in more than one year but less than half of all study years. Species that were rarely observed and were seen during only one year included emerald shiner, brown trout, quillback, walleye, coregonids (bloater and lake herring), and shorthead redhorse. The 10 taxa that were frequently or commonly observed composed the bulk of the observations of fish. The remaining 12 taxa were seen too infrequently to make detailed inferences based on underwater observations.

A total of 72 species of fish were identified among the 1.1 million fish collected during 1973-1982 field studies near the Cook Plant (Tesar and Jude 1985) and 5.8 million fish impinged on its traveling screens during 1975-1982 (Thurber and Jude 1985). Therefore, about one third (31%) of the species documented in the study area by Cook Plant studies were observed by divers. These observations suggest that a large number of the species that occurred in

Table 9. Annual relative ranked abundance of fish observed during all diving in southeastern Lake Michigan near the D. C. Cook Nuclear Plant, 1973-1982. Fish were grouped according to frequency of observation. Blanks indicate no observation. Common names of fish assigned according to Robins et al. (1980).

| Species | No. yrs observed | Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 |
| Frequent | | | | | | | | | | | |
| Alewife | 10 | 2 | 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Yellow perch | 10 | 3 | 4 | 3 | 4 | 3 | 3 | 2 | 4 | 2 | 2 |
| *Cottus* spp.[1] | 10 | 5 | 1 | 2 | 2 | 5 | 4 | 5 | 5 | 5 | 4 |
| Johnny darter | 10 | 6 | 3 | 4 | 3 | 2 | 4 | 4 | 6 | 4 | 6 |
| Spottail shiner | 10 | 1 | 2 | 5 | 6 | 7 | 7 | 3 | 3 | 7 | 5 |
| Common | | | | | | | | | | | |
| Trout-perch | 9 | 4 | 5 | 6 | 7 | | 8 | 8 | 8 | 3 | 7 |
| Common carp | 9 | | 7 | 7 | 5 | 6 | 6 | 6 | 7 | 6 | 3 |
| Rainbow smelt | 8 | | | 8 | 8 | 4 | 2 | 7 | 2 | 8 | 7 |
| Burbot | 7 | | 8 | 9 | 9 | 9 | | 9 | 9 | | 9 |
| White sucker | 7 | | | 9 | 10 | 9 | 10 | | 10 | 9 | 9 |
| Uncommon | | | | | | | | | | | |
| Largemouth bass | 3 | | | 9 | | 8 | | | | | 9 |
| Lake trout | 3 | | 8 | | | | | | 10 | 9 | |
| Channel catfish | 2 | | 8 | | | | | | | | 9 |
| Black bullhead | 2 | | 8 | | | | | | 10 | | |
| Smallmouth bass | 2 | | | 9 | 10 | | | | | | |
| Longnose sucker | 2 | | | | | | 9 | 10 | | | |
| Rare | | | | | | | | | | | |
| Emerald shiner | 1 | | 8 | | | | | | | | |
| Brown trout | 1 | | | | | | | | 10 | | |
| Quillback | 1 | | | | | | | 10 | | | |
| Walleye | 1 | | | | | | 10 | | | | |
| *Coregonus* spp.[2] | 1 | | | | | | | | | | 9 |
| Shorthead redhorse | 1 | | | | | | | | | | 9 |
| Total taxa | | 6 | 12 | 12 | 11 | 10 | 11 | 11 | 13 | 10 | 14 |

1 Includes both *C. cognatus* (slimy sculpin) and *C. bairdi* (mottled sculpin).

2 Includes both *C. artedii* (cisco or lake herring) and *C. hoyi* (bloater).

the area were rare and that diver observations of fish were limited to the more abundant species. The 5 fish taxa most frequently observed by divers were also among the 10 fish taxa most frequently collected in field and impingement samples.

Total number of fish taxa observed each year varied from 6 to 14 (Table 9). If 1973 data are ignored (both the diving methodology and schedule were incomplete that year), numbers of fish taxa observed ranged from 10 to 14, annually. Considering that 11 taxa were seen at least 7 out of 10 years, and 5 taxa were seen every year, the diversity of species regularly observed by divers was low in comparison with total number of species occurring in the area. However, the most abundant species in field and impingement samples were nearly always observed by the divers. These observations suggest that diving is effective for documenting the presence of abundant species but ineffective for studying rare species.

Fish species observed by divers could be divided into two categories based on their behavior and response to the presence of the Cook Plant. The first category described orientation of fish in the water column - pelagic or demersal. The second category was related to the response of fish to the physical presence or aspects of plant operation - attracted or indifferent (species repelled by the plant were not discerned by this study) (see Tesar and Jude 1985). Four combinations of these behavior-response categories were represented in the observational data base: pelagic fish that were attracted to the plant (pelagic-attracted), pelagic fish that were indifferent to the plant (pelagic-indifferent), demersal fish that were attracted to the plant (demersal-attracted), and demersal fish that were indifferent to the plant (demersal-indifferent).

Pelagic fish that appeared to be attracted to the in-lake structures or operation of the plant included yellow perch and common carp and possibly largemouth bass, smallmouth bass, and walleye. Pelagic species that appeared generally indifferent to the in-lake presence or operation of the plant included alewife, spottail shiner, trout-perch, rainbow smelt, lake trout, emerald shiner, brown trout, and coregonids. Demersal fish that appeared to be attracted to the in-lake presence or operation of the plant included sculpins, burbot, channel catfish, and black bullhead. Demersal fish that appeared indifferent to the in-lake presence or operation of the plant included johnny darter, white sucker, longnose sucker, quillback, and shorthead redhorse.

Inspection of relative ranked abundance of fish within and among years revealed that in most years alewife was most abundant. Yellow perch always attained one of the next three ranks (second-fourth). Alewife, yellow perch, johnny darter, spottail shiner, and sculpins always comprised at least four of the top five ranks each year.

Relative ranked abundance of fish species observed during transect swims along the base of the south intake structure (Table 10) generally paralleled that established for total dives (Table 9). Total number of fish species observed each year ranged from five to nine. Number of species observed during transect dives was always less than the total number observed for any given year, primarily because the observational effort for transect swims was much less than for total dives. However, during transect swims, observations were focused on the bottom and did not extend above bottom beyond the range of visibility, which was usually between 2 and 3 m (Table 4). Consequently, a slightly higher percentage (44%) of those species classified as demersal was

Table 10. Annual relative ranked abundance of fish observed during duplicate observations made during transect swims in southeastern Lake Michigan, 1975-1982. Observations were made by two divers swimming side-by-side for 10 m along the base of the south intake structure of the D. C. Cook Nuclear Plant. Each diver examined an area 1 m wide; observations were summed and then ranked for the total area (20 $m^2$) examined. Fish were grouped according to frequency of observation. Blanks indicate no observation. Common names of fish assigned according to Robins et al. (1980).

| Species | No. yrs observed | Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 |
| Frequent | | | | | | | | | |
| Alewife | 8 | 1 | 1 | 1 | 1 | 1 | 4 | 6 | 2 |
| Yellow perch | 8 | 3 | 4 | 4 | 2 | 2 | 3 | 4 | 1 |
| *Cottus* spp.[1] | 8 | 2 | 2 | 3 | 5 | 3 | 2 | 1 | 3 |
| Common | | | | | | | | | |
| Johnny darter | 7 | 4 | 3 | 2 | 3 | 5 | 6 | 3 | |
| Spottail shiner | 7 | 5 | 5 | | 4 | 4 | 5 | 4 | 4 |
| Rainbow smelt | 5 | | 6 | 5 | 6 | | 1 | 2 | |
| Trout-perch | 4 | | 8 | | | 6 | 7 | 7 | |
| Uncommon | | | | | | | | | |
| Burbot | 3 | | 6 | | | 6 | 7 | | |
| Rare | | | | | | | | | |
| Black bullhead | 1 | | | | | | 7 | | |
| Total taxa | | 5 | 8 | 5 | 6 | 7 | 9 | 7 | 4 |

1 Includes both *C. cognatus* (slimy sculpin) and *C. bairdi* (mottled sculpin).

seen than of those classified as pelagic (38%). Of those species frequently or commonly observed during the total diving effort, only burbot and white sucker did not appear in these same observational frequency categories during transect dives. These two species were not abundant and never attained a rank higher than ninth in total dives conducted after 1974.

As with total dives, alewife was the most frequently observed fish species during transect dives. Sculpins displaced yellow perch as the second-most abundant fish species observed during transect swims. This was not unexpected considering the generally high abundance and demersal behavior of sculpin. Yellow perch was generally the third-most abundant species seen during transect swims. Johnny darter and spottail shiner occupied a lower frequency category for transect dives than for total dives. However, the significance of this shift was relatively inconsequential considering the overall abundance of these two species in the study area. No pelagic species classified as uncommon or rare among total diving observations (Table 9) were observed during transect swims (Table 10).

In addition to total diving observations (summarized from Appendix 1) and transect observations (summarized from Appendix 2), summary data are presented from standard series field sampling (Tesar and Jude 1985) and studies on impingement of fish on the Cook Plant traveling screens (Thurber and Jude 1984, 1985) for 10 species of fish: yellow perch, common carp, alewife, spottail shiner, trout-perch, rainbow smelt, sculpins, burbot, johnny darter, and white sucker. The remaining 12 species of fish observed during underwater studies at the Cook plant were seen too infrequently to permit meaningful analyses based on observational data. Species discussions are

grouped according to the four behavioral categories noted earlier: pelagic-attracted, pelagic-indifferent, demersal-attracted, and demersal-indifferent.

Pelagic-Attracted --

The species complex of diver-observed pelagic fish that appeared to be attracted to the in-lake structures or plant operation included yellow perch, common carp, and possibly largemouth bass, smallmouth bass, and walleye. Sufficient evidence (Tables 9, 10) was compiled during the study to infer the attraction of yellow perch and common carp to the plant. The attraction of the other three species to the plant was hypothesized more from general knowledge of the species and their habits than from empirical data.

Yellow perch was usually the second- or third-most abundant species observed during all dives and transect swims and was never lower than fourth (Fig. 9). It was also among the five most abundant species in field and impingement samples. During 1973-1977, the relative ranked abundance of yellow perch fluctuated among the four sampling categories. A distinct decline in abundance occurred in field and impingement samples between 1977 and 1978 and was followed by a steady increase in relative abundance. Although this pattern was not reflected in diving observations, yellow perch were frequently observed during 1978-1982 underwater studies.

The disparity in trends of relative ranked abundance between field and impingement sampling and all dives and transect swims may be explained by the documented affinity that yellow perch have for rough substrate in the generally smooth, sandy-bottom areas of inshore eastern Lake Michigan (Dorr 1982, Rutecki et al. 1985). The attraction of yellow perch to the riprap zone, established through underwater observations, elevated their local

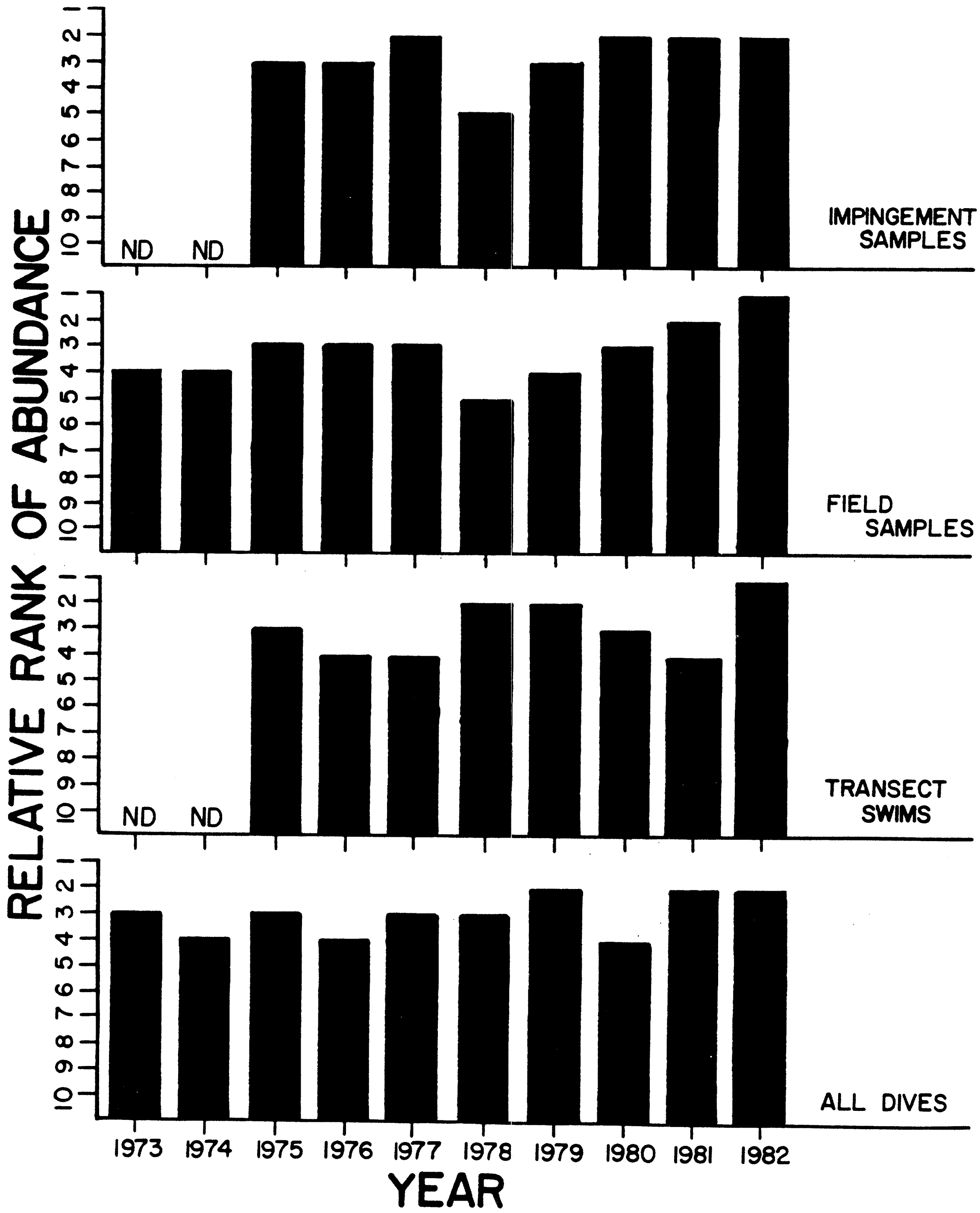


Fig. 9. Comparison of relative ranked abundance of yellow perch observed by divers during all dives (1973-1982) and transect swims (1975-1982), collected in standard series field samples (1973-1982), and impinged (1975-1982) at the D. C. Cook Nuclear Plant, southeastern Lake Michigan. Ordinate scale is inverted and extends from lowest to highest rank of relative abundance. Blanks indicate zero observations or catch; ND = no diving or sampling.

abundance in comparison with field sampling, which was conducted only in areas of sand substrate (Fig. 9). The parallel in ranked abundance of yellow perch in impingement samples with that of field samples suggests that rate of impingement was related more closely to their general field abundance than their attraction to the riprap zone.

Most yellow perch observed by divers were adults; juveniles were seldom seen, although they were abundant in field and impingement samples. A distinct pattern in the temporal distribution of yellow perch was noted. Adult fish moved inshore into the study area during April. This movement appeared to be more closely related to inshore spawning than initial feeding, because most fish did not eat until spawning was completed (Dorr 1982). Spawning occurred in the study area during late May, and yellow perch remained concentrated in the riprap zone throughout the summer. Feeding commenced shortly after spawning was completed. During fall, yellow perch moved offshore and were seldom seen by divers during October dives. Largest numbers of adult fish were collected in field samples during May-August. Young-of-the-year were collected in trawl and seine hauls during late summer and fall and in impingement samples during fall and winter.

At least two patterns in the spatial distribution of yellow perch were discerned by this and related studies. The first pattern was the seasonal inshore migration of adults in spring and an offshore migration during fall. These movements were documented by underwater observations, field studies (Tesar and Jude 1985), and impingement studies at the Cook Plant (Thurber and Jude 1984, 1985). Juvenile yellow perch inhabited the inshore area throughout fall and winter, as evidenced by their impingement at the Cook Plant during these months. The second pattern in spatial distribution was the

concentration of adult fish in areas of rough substrate. As water temperatures increased in spring, adult fish moved inshore and onto natural and artificial reefs present in the area. Although Dorr (1982) compiled some evidence that limited movement off the reefs occurred after spawning, the bulk of the fish appeared to remain close to areas of rough substrate. Yellow perch were never observed at smooth-bottomed reference stations; however, they were commonly collected there during summer months in trawls and gill nets (Tesar and Jude 1985).

Adult yellow perch were distinctly day-active and at night rested on the bottom, often in crevices formed by the riprap. As further evidence of yellow perch nocturnal inactivity, divers were able to grasp fish at night. During the day, fish on several occasions were fed crayfish by divers. Fish formed loose schools composed of various sizes of fish with a length range often exceeding 100 mm. Random swimming or "milling" was typical; closely coordinated group movements were not observed. Both solitary fish and schools remained within 1-3 m of the bottom or the plant structures.

Common carp was the sixth or seventh most commonly observed fish in the study area; they were seen during all years except 1973. Field sampling and impingement of common carp at the plant suggested that the overall abundance of this species in the study area was relatively constant during the study period (Fig. 10). However, several patterns and changes in the temporal and spatial distribution of common carp were evidenced by underwater observations and other studies of adult and larval fish.

Diving observations documented a distinct increase in abundance of these fish near the plant following the start-up of warm-water discharge. This local increase was paralleled in field study catches (Tesar and Jude 1985). Of

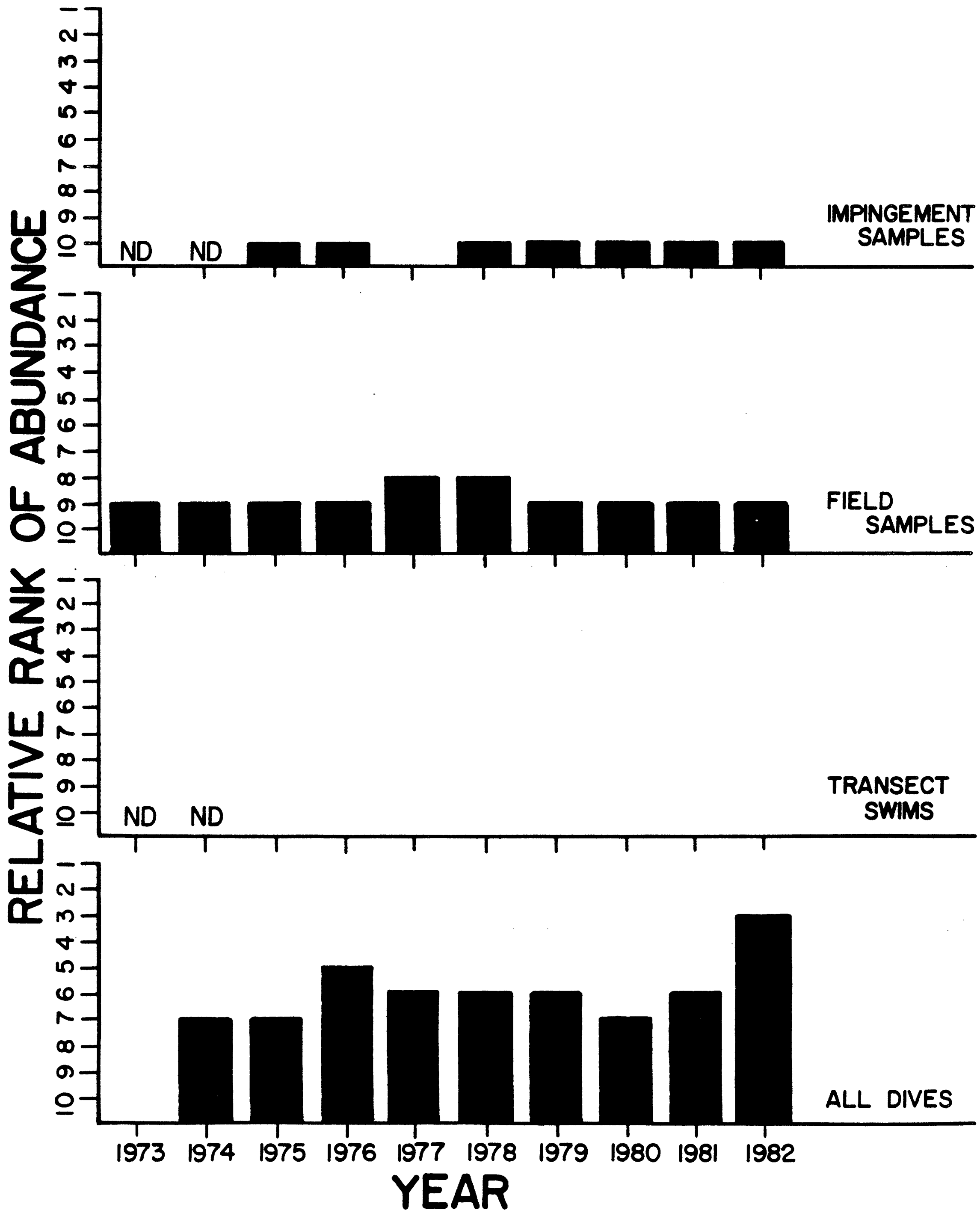


Fig. 10. Comparison of relative ranked abundance of common carp observed by divers during all dives (1973-1982) and transect swims (1975-1982), collected in standard series field samples (1973-1982), and impinged (1975-1982) at the D. C. Cook Nuclear Plant, southeastern Lake Michigan. Ordinate scale is inverted and extends from lowest to highest rank of relative abundance. Blanks indicate zero observations or catch; ND = no diving or sampling.

the more than 460 common carp observed during the study, none was seen in 1973, and only two were seen in 1974, preoperational years. Nine fish were seen in 1975. From 1976 to 1982, numbers of fish observed annually varied from 14 to more than 200 (Appendix 1) and averaged about 40. Larval common carp were never collected in preoperational years 1973-1974 at the Cook Plant but were collected and entrained at the plant during its first operational year (1975) and in most later years of the study (Noguchi et al. 1985). Larval common carp were not collected during 1973-1979 at reference stations located 7 km south of the Cook Plant near Warren Dunes State Park, but a few larvae were taken at these reference stations during the last years of the study. Bimber et al. (1984) attributed this uneven distribution of larval common carp to spawning in the warm-water plume of the plant. Although common carp were attracted to the plant, annual impingement was low and ranged from zero to 34 fish between 1975 and 1982 (Thurber and Jude 1985). This suggests that the fish were not particularly susceptible to entrapment at the intake structures, probably because they concentrated near the discharge area.

Further evidence of attraction of common carp to the warm-water plume was that of the more than 460 fish observed by divers, only 12 were seen at the intakes and none was seen at reference stations. All other observations were made in the vicinity of the discharge stations. On several occasions during late spring and summer, divers in boats and on shore observed schools of common carp swimming in the vicinity of the discharge structures; none was seen in the vicinity of the intake structures.

Divers observed common carp in greatest abundance during the period May-August. Most fish taken in field samples were collected during the same period. However, the impingement of common carp did not show any temporal

pattern, probably because their susceptibility was low even when they were abundant in the vicinity of the discharge.

Common carp were day-active and seldom seen at night. The few fish that were observed during night dives were on the bottom, solitary, and inactive. Most often, common carp were seen in groups rather than individually. Most diver-observed fish were swimming randomly in the vicinity of the discharge structures. They often approached the divers closely and on several occasions swam into the divers. As noted earlier, their feces were often abundant at the closest reference station north of the discharges (north reference station I - Fig. 1) but were rarely seen at other diving stations.

Largemouth bass, smallmouth bass, and walleye were seen three times, twice, and once, respectively, during the study (Table 9) and never during transect swims (Table 10) or at reference stations. In all instances, the fish were seen in close proximity to the intake or discharge structures. It is believed that these fish were attracted to the structures and not just the surrounding rough substrate, perhaps because of the elevated profile that the structures presented. All fish were seen during the warm-water months (May-September) and during the day. Only solitary fish were observed.

Pelagic-Indifferent --

The species complex of diver-observed pelagic fish indifferent to the in-lake structures or plant operation included alewife, spottail shiner, trout-perch, rainbow smelt, lake trout, emerald shiner, brown trout, and unidentified coregonids (bloater or lake herring). Sufficient observational data were compiled on the first four species to permit meaningful discussion

and inferences. The remaining fish species were seen infrequently and little can be concluded based on these sightings.

Alewife was generally the most abundant species observed and collected in the study area. Comparison of summary data (Fig. 11) revealed few fluctuations in annual relative ranked abundance within each of the four data categories. Field sampling data and other evidence indicated that the abundance of alewife in the study area declined during 1980-1982 relative to previous years (Jude and Tesar 1985). This decline was paralleled by transect swim data where annual observational effort was standardized. The decline was not reflected in data compiled from all dives. It is possible that the small annual variation in total diving effort that occurred during 1975-82 may have obscured this decline, although more dives were conducted annually during 1975-1979 (17-19 dives yearly) than during 1980-1982 (15-17 dives yearly). Another explanation may be that large schools of alewives were rarely encountered during transect swims; whereas, they were frequently encountered during non-transect diving. Also, estimation of these large schools of fish (often containing more than 1,000 individuals) may have smoothed and obscured yearly variations in abundance. Nonetheless, alewife were the most abundant and ubiquitously distributed fish in the study area.

No patterns or trends were observed in the spatial distribution of alewife during the underwater study. Individual and schooling fish were observed at both riprap and reference stations.

A distinct temporal pattern was noted in the abundance of alewife. Alewife were rarely observed during April but were usually seen in great abundance during May-June, and the impingement of alewives usually peaked during the same period. Adult fish were collected in field samples in

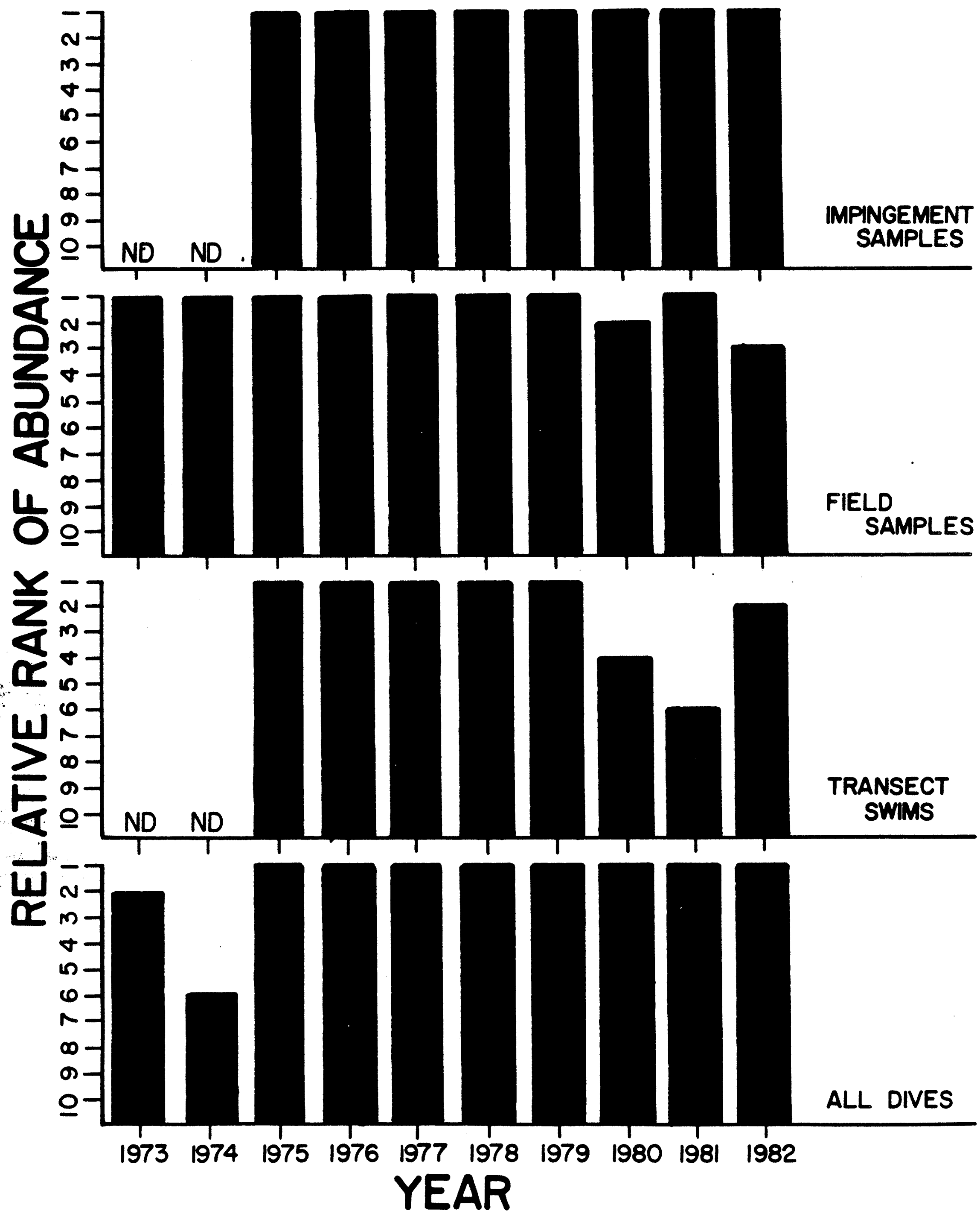


Fig. 11. Comparison of relative ranked abundance of alewives observed by divers during all dives (1973-1982) and transect swims (1975-1982), collected in standard series field samples (1973-1982), and impinged (1975-1982) at the D. C. Cook Nuclear Plant, southeastern Lake Michigan. Ordinate scale is inverted and extends from lowest to highest rank of relative abundance. Blanks indicate zero observations or catch; ND = no diving or sampling.

greatest abundance during the same period. The abundance of alewife in the study area during this period corresponded with their spring migration from offshore areas of the lake to the more rapidly warming inshore waters where they subsequently spawned during late May–August. Adult fish continued to be observed throughout the summer, although numbers of fish observed were reduced from peak levels that occurred during May–June. Numbers of adult fish seen during October were always low and corresponded with the fall migration of fish to offshore areas.

Young-of-the-year (YOY) alewives were usually first observed by divers during August or September and large schools were often seen during September-October. This fall pattern was paralleled by an increase in impingement of YOY alewives, which by this time were large enough (>50 mm) to be retained by the traveling screens (Thurber and Jude 1984, 1985). Young-of-the-year fish were often seined in great abundance during August-September.

When observed, schools of both adult and YOY alewives were distributed throughout the water column. Schooling of adult fish was observed only during the day. Movements of individual fish were rarely coordinated into simultaneous group movements and considerable "milling" of fish occurred. Solitary fish were commonly seen. At night, fish often occurred in groups or clustered at various locations around the intake structure. Although the fish were active at night, swimming appeared undirected, and fish could often be approached closely or touched by divers. Schools of YOY alewife were only observed at night and were closer to the surface than the bottom. On several occasions, adult fish were observed to group near the intake structure and face into the oncoming current. Some individuals made snapping or sucking

(not coughing) movements with their mouth and may have been ingesting zooplankton in the water.

Spottail shiner was included among the group of frequently observed species; they were seen during all years of the study. It was also included among the five most-abundant species in field and impingement samples. The relative ranked abundance of spottail shiners in impingement catches fluctuated somewhat among years but remained nearly constant for field samples (Fig. 12). A nearly constant level of relative abundance was also reflected in transect-swim data. Pooled observations from all dives suggested that the relative abundance of spottail shiners declined during the late 1970s, but this decline was not reflected among the other three data bases. Therefore, it was concluded that the relative ranked abundance of spottail shiners remained relatively unchanged during the study.

Spottail shiners were not observed at reference stations, but field and impingement studies did not indicate any notable differences in spatial distribution. However, diving was more extensive in the riprap area and the small size of the fish made them difficult to see off bottom, particularly when visibility was low. No other evidence of substrate-selective behavior or attraction to plant structures or operation was compiled during the underwater studies.

A distinct temporal pattern was noted in the seasonal distribution of spottail shiners as observed by divers. Fish were rarely seen in the study area in April and October and were most often observed during June-August. A similar pattern of seasonal abundance was reflected in field catches of spottail shiner (Tesar and Jude 1985). This temporal pattern of abundance resulted from movement of fish into the inshore area of the lake during June-

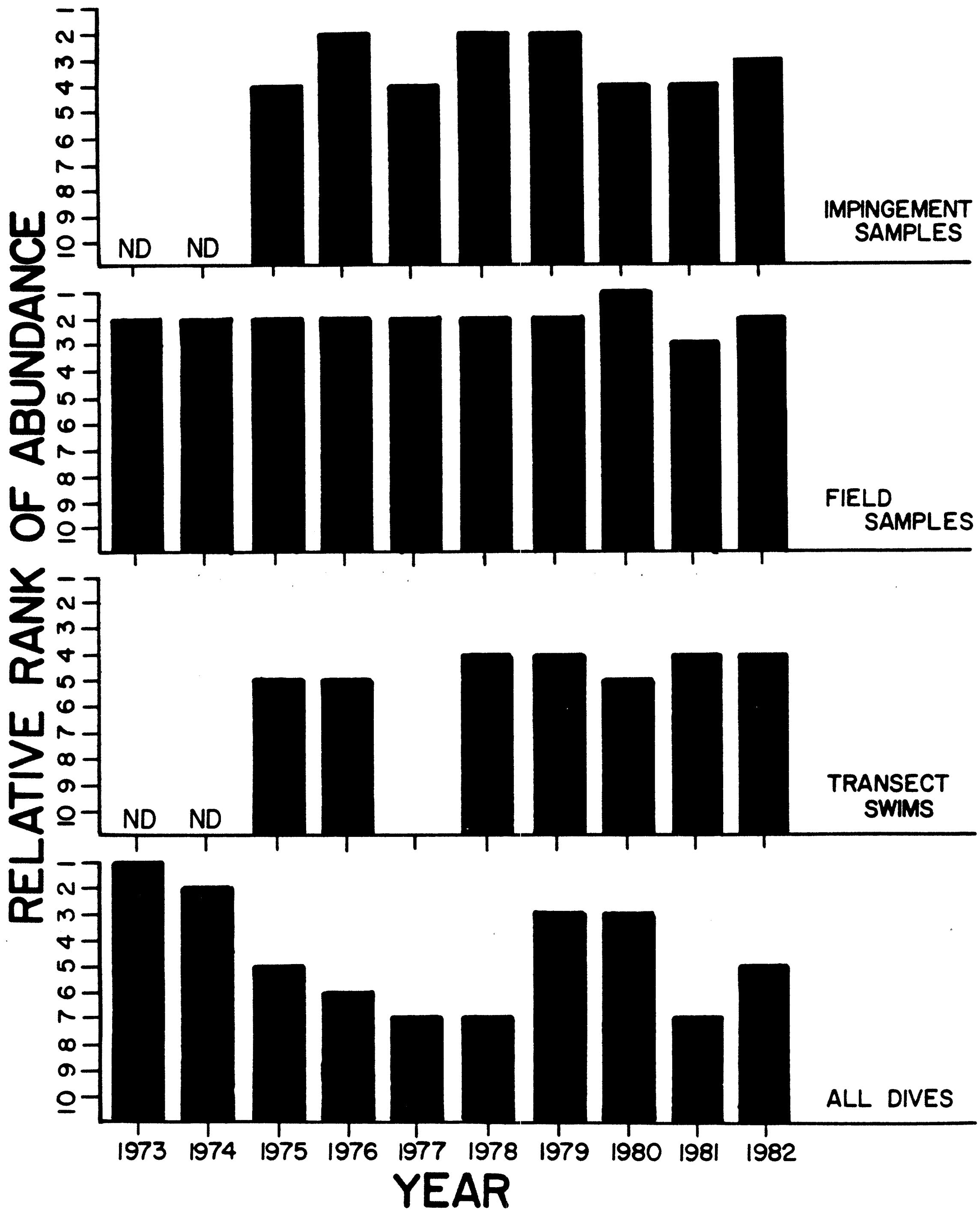


Fig. 12. Comparison of relative ranked abundance of spottail shiners observed by divers during all dives (1973-1982) and transect swims (1975-1982), collected in standard series field samples (1973-1982), and impinged (1975-1982) at the D. C. Cook Nuclear Plant, southeastern Lake Michigan. Ordinate scale is inverted and extends from lowest to highest rank of relative abundance. Blanks indicate zero observations or catch; ND = no diving or sampling.

August when spawning and feeding occurred. During fall, fish moved offshore. Although peak impingement of spottail shiners usually occurred during May-August, fish were often impinged in large numbers throughout the year. The relatively high impingement of fish during periods of low field abundance may have resulted from their seeking shelter near the structures during fall and winter storms or from their general disorientation and increased susceptibility to entrapment during these periods of severe inshore turbulence.

Spottail shiners were more commonly observed at night than during the day, but this was believed to be more the result of increased vulnerability to approach and observation at night because of reduced light than to actual increases in nocturnal activity. This belief was based on the observed similarity between daytime and nighttime behavior, including levels of activity and alertness.

Most spottail shiners seen by divers were adults; juveniles and YOY fish were rarely observed. Although schooling probably occurs for this species (Nursall 1973), it was not observed by divers. No differences in diel activity were noted. Fish were seen throughout the water column and did not appear attracted to the structures or riprap.

During a 1973 night dive on the south intake structure, several thousand spottail shiners were observed, some of which were seen to broadcast their eggs over the periphyton growing on top of the structure. Spawning was not observed in subsequent years, but spottail shiners were usually seen in considerable abundance during June night dives in the vicinity of the structures. The fish are abundant and widely distributed in Lake Michigan, and no evidence supporting substrate-selective spawning was compiled during

this study. Spottail shiner eggs are demersal, adhesive, and probably randomly broadcast without regard to substrate configuration or composition. Most spawning occurs in the <3 m depth zone (Tesar and Jude 1985, Noguchi et al. 1985).

Trout-perch were seen during 9 of the 10 study years (Table 9) but usually not in great abundance, i.e., more than 60 fish during any set of monthly dives (Appendix 1). Trout-perch were never seen in abundance during transect swims along the base of the south intake structure (Table 10). This was attributed to their tendency to remain off-bottom during the day, which encompassed half of the transect diving effort. The relative ranked abundance of trout-perch remained similar among years for impingement and field samples and transect swims (Fig. 13). A decline in relative ranked abundance occurred in data summarized from all dives, but this decline was not reflected in the other three data sets.

Although trout-perch were never seen at reference stations, no evidence was compiled during field sampling and impingement studies to suggest that they were attracted to the plant structures or riprap or by plant operation. A seasonal pattern was evident in the temporal distribution of the fish. Generally, trout-perch were seen most frequently during May-August; sightings during other months were rare. Both field and impingement catches of trout-perch were largest during May-September and small during the winter. No pattern was noted in the diel distribution of fish as observed by divers.

All fish observed were solitary. During the day, trout-perch were alert and active and were difficult to approach. At night, most fish were seen within 1-2 m of the bottom, and although they were active, swimming was

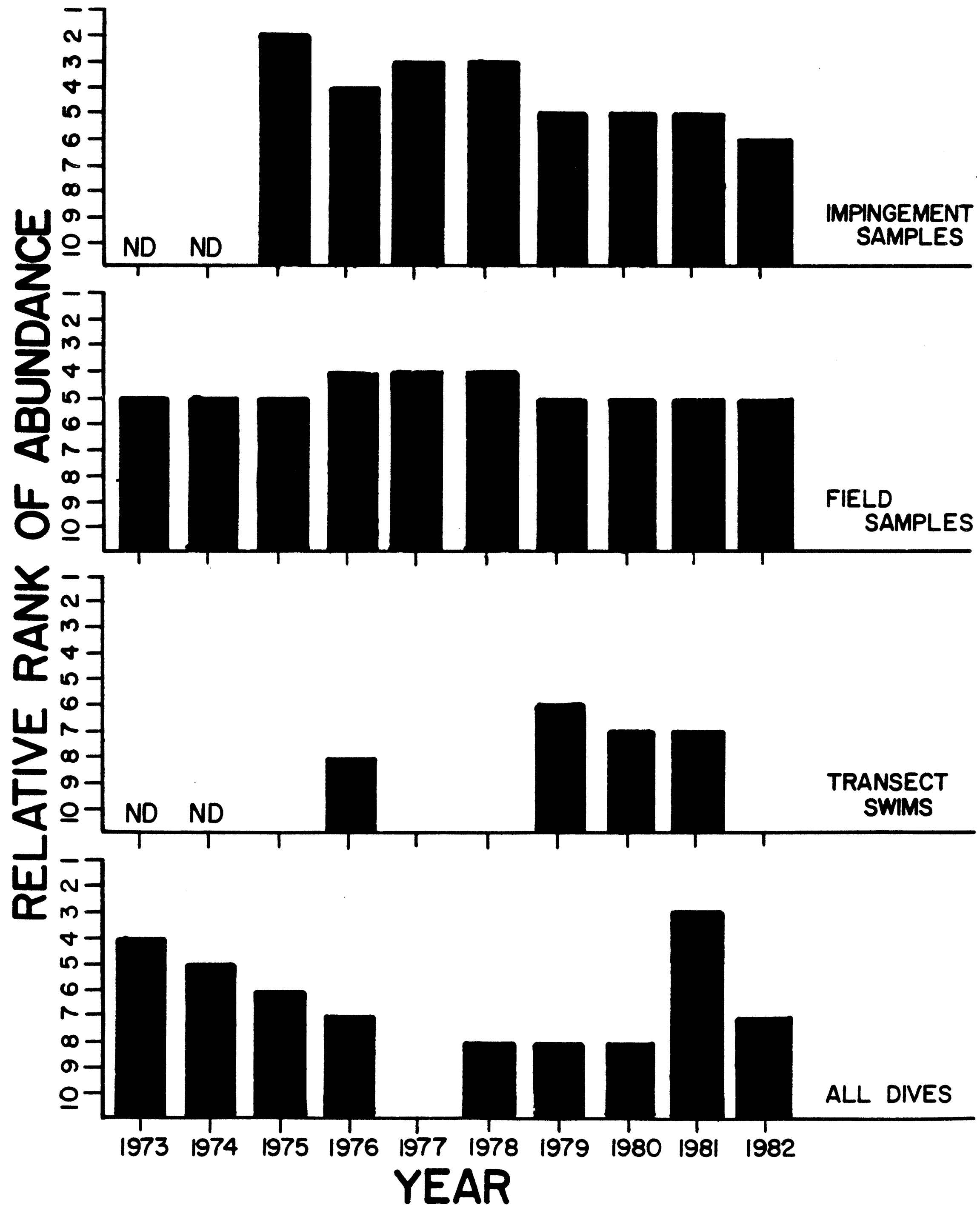


Fig. 13. Comparison of relative ranked abundance of trout-perch observed by divers during all dives (1973-1982) and transect swims (1975-1982), collected in standard series field samples (1973-1982), and impinged (1975-1982) at the D. C. Cook Nuclear Plant, southeastern Lake Michigan. Ordinate scale is inverted and extends from lowest to highest rank of relative abundance. Blanks indicate zero observations or catch; ND = no diving or sampling.

undirected and sporadic, and the fish appeared disoriented and often darted against the bottom when approached.

Rainbow smelt were seen during 8 of the 10 study years. Adult fish were never seen in abundance although schools of YOY fish were occasionally observed during September and October. The relative ranked abundance of rainbow smelt remained similar among years for field samples but varied among impingement samples, transect swims, and overall diving observations (Fig. 14).

A pronounced seasonal pattern was noted in the temporal distribution of rainbow smelt. Fish were most commonly collected in field and impingement samples during the early spring when the fish moved inshore to spawn and during fall after the lake water cooled. Exceptions to this pattern occurred during summer when upwellings brought fish associated with offshore cold-water masses into the study area. Much of the variability among years for diving observations was attributed to the sporadic occurrence of upwellings inshore during summer months and the association of rainbow smelt with these masses of cold water. Rainbow smelt were not observed at reference stations, but no pattern or differences in spatial abundance of fish were established during the underwater studies. Quite likely, fish avoided the warm-water discharge area and plume, but this was undoubtedly a local effect and had negligible impact on the overall inshore distribution or abundance of rainbow smelt.

Adult fish were seen more often at night than during the day. Fish were solitary, active, and alert. They were usually seen off-bottom and did not exhibit any affinity for the structures or riprap. Schooling was not observed for adult fish, but small schools of YOY fish were seen during some night dives in September and October.

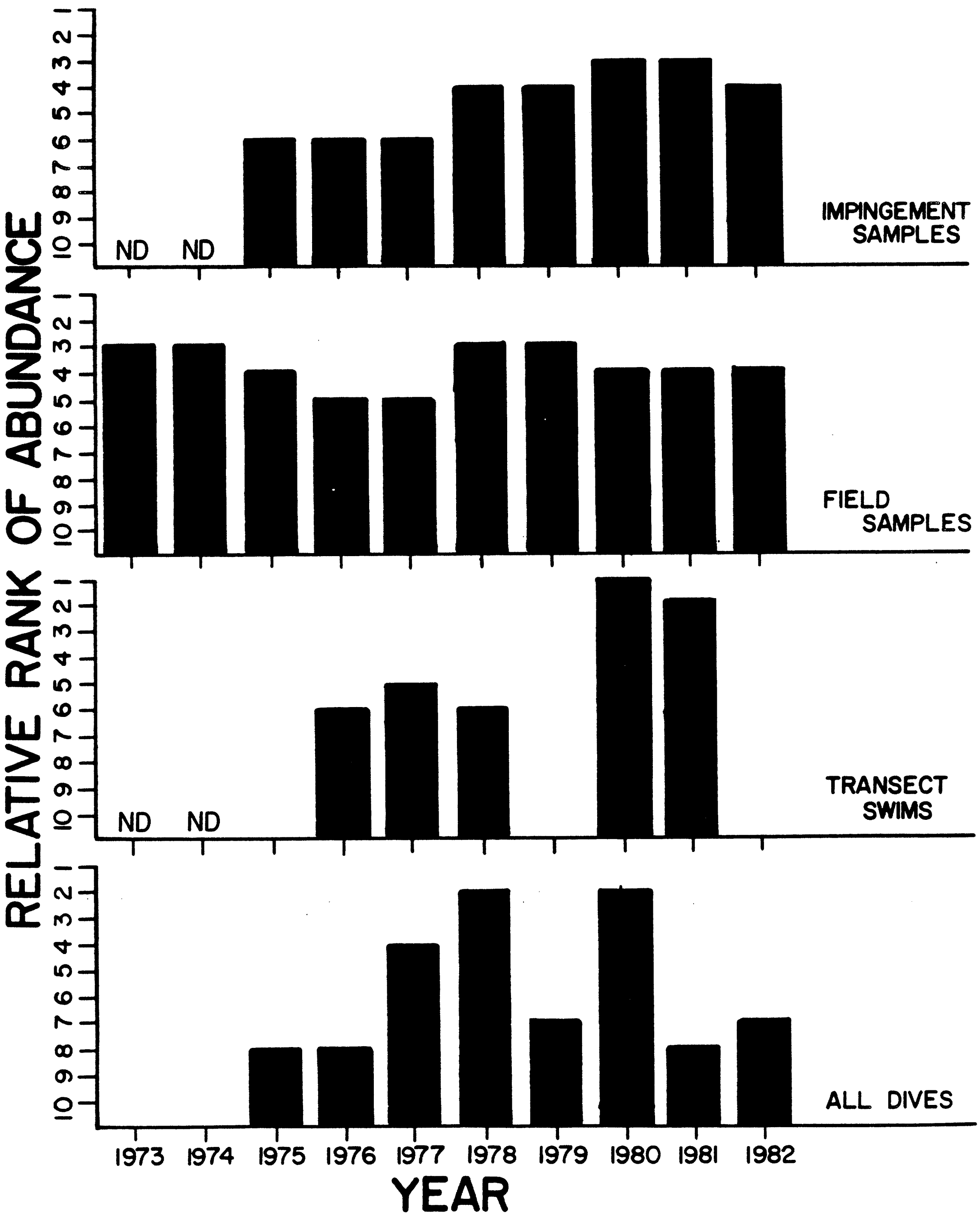


Fig. 14. Comparison of relative ranked abundance of rainbow smelt observed by divers during all dives (1973-1982) and transect swims (1975-1982), collected in standard series field samples (1973-1982), and impinged (1975-1982) at the D. C. Cook Nuclear Plant, southeastern Lake Michigan. Ordinate scale is inverted and extends from lowest to highest rank of relative abundance. Blanks indicate zero observations or catch; ND = no diving or sampling.

Lake trout were seen during three of the study years, and emerald shiner, brown trout, and unidentified coregonids (bloaters or lake herring) were seen during one year. Brown trout, emerald shiner, and unidentified coregonids were seen too infrequently to permit meaningful inferences regarding these fish. However, no evidence was compiled during the underwater studies which indicated that any of these four species of fish were attracted or repelled by presence of in-lake structures or riprap or by operation of the plant.

In a separate study, lake trout were seen in abundance in the Cook Plant intake area and at 6 m in an area of rough clay substrate 5 km north of the Cook Plant off the Grand Mere Lakes during night dives conducted on 14 November 1977. The fish were active, alert, and occurred in groups, but spawning was not observed. The substrate was examined closely, but no eggs were found (unpublished data, Great Lakes Research Division, University of Michigan, Ann Arbor, Michigan). The only other observations of lake trout were incidental sightings of solitary fish made primarily at night. During 9-10 November 1975, an intense storm passed through the Great Lakes region, and thousands of windrowed lake trout eggs were observed along the beach at the Cook Plant (personal communication, J. Barnes, Indiana & Michigan Power Company, Bridgman, Mich.) as well as near Charlevoix, Michigan (personal communication, T. Stauffer, Marquette Fisheries Research Station, Marquette, Michigan). However, lake trout eggs were never observed by divers or taken in entrainment samples pumped from the plant forebay. On a few occasions, salmonid eggs were found in the stomachs of slimy sculpins impinged at the Cook Plant, but the species and location where the eggs were spawned and eaten were not established. During 10 years of study, no evidence was compiled to suggest that lake trout spawned on the Cook Plant riprap.

Demersal-Attracted --

The species complex of diver-observed demersal fish that appeared to be attracted to the in-lake structures or plant operation included sculpin (*Cottus cognatus* or *C. bairdi*), burbot, channel catfish, and black bullhead. We believe sculpins and burbot were attracted to the plant area. The attraction of channel catfish and black bullhead to the plant area was hypothesized more from general knowledge of the species and their habits than from empirical data.

Three species of sculpin were found in field and impingement samples collected in the study area: *Cottus cognatus* or slimy sculpin, *C. bairdi* or mottled sculpin, and *Myoxocephalus thompsoni* or deepwater sculpin. Deepwater sculpins were rarely collected and are excluded from this discussion. Both slimy sculpins and mottled sculpins were identified in field and impingement catches made in the study area (Tesar and Jude 1985; Thurber and Jude 1984, 1985). There was some evidence that mottled sculpin were more abundant inshore during summer than slimy sculpin. However, it was not possible for divers to distinguish between the two species; therefore, they are treated as a single group and referred to collectively as sculpins.

Sculpins were seen during every year of the study for both total standard series dives (Table 9) and transect swims along the base of the south intake structure (Table 10). Overall, it ranked as the fourth- or fifth-most abundant fish species seen by divers during the study. Comparison of the relative ranked abundance of sculpins observed during all dives and transect swims with their ranked abundance in impingement and field samples indicated the attraction of this fish to the plant area (Fig. 15). Sculpins ranked as only the sixth- to ninth-most abundant fish in field samples that were

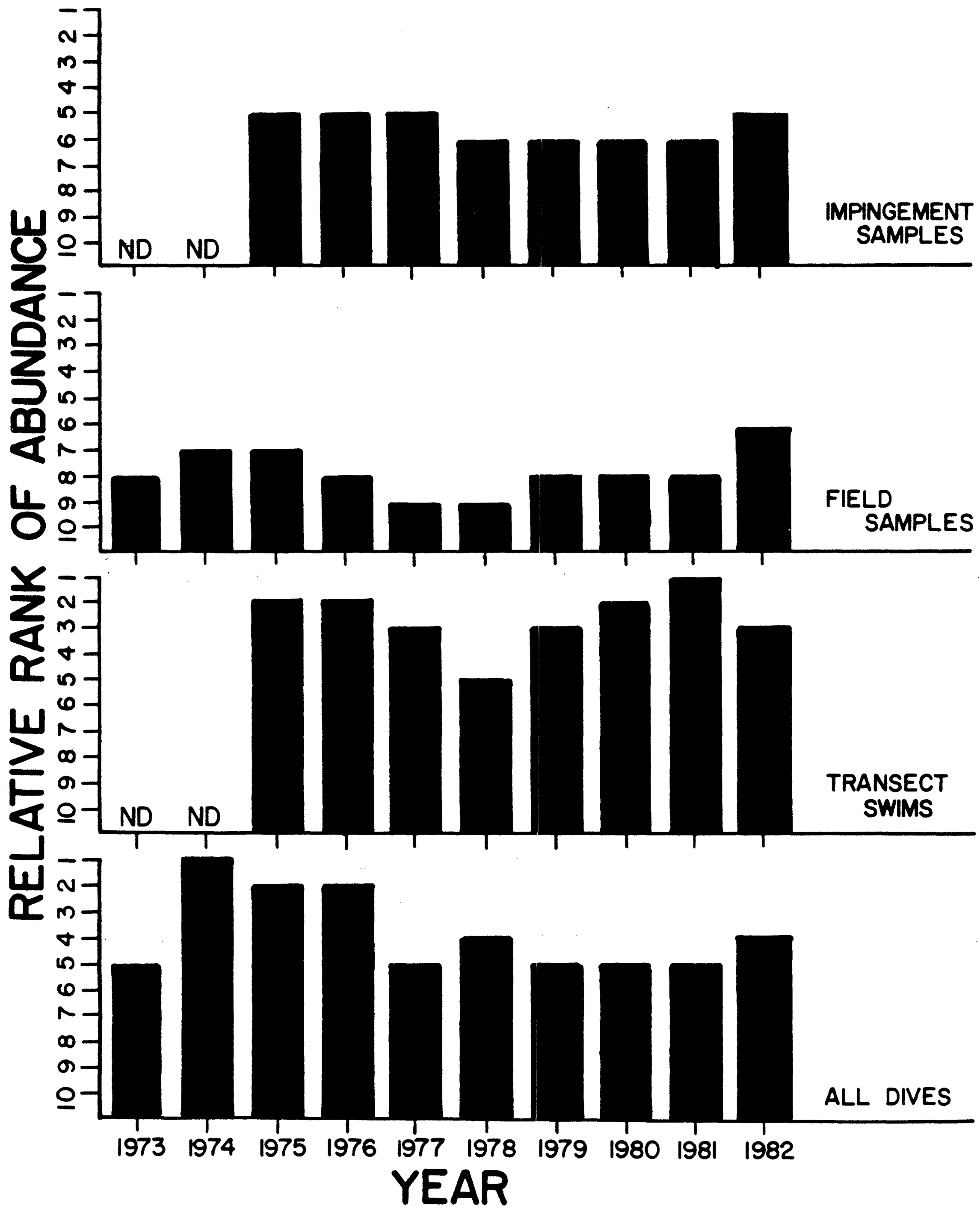


Fig. 15. Comparison of relative ranked abundance of slimy sculpins (*Cottus cognatus* or *C. bairdi*) observed by divers during all dives (1973-1982) and transect swims (1975-1982), collected in standard series field samples (1973-1982), and impinged (1975-1982) at the D. C. Cook Nuclear Plant, southeastern Lake Michigan. Ordinate scale is inverted and extends from lowest to highest rank of relative abundance. Blanks indicate zero observations or catch; ND = no diving or sampling.

collected exclusively in sand-bottom areas. But in impingement samples, they ranked as the fifth to sixth most abundant species and were always among the first five most abundant species in transect and total diving observations. Sculpins are cryptozoic in their behavior which is reflected in their preference for rugose substrate (Scott and Crossman 1973). The interstices among the riprap provided ideal shelter and habitat for these fish. Sculpins were probably attracted to the riprap and the protection it afforded rather than to any specific factor associated with plant operation (e.g., circulation, heated-water discharge, turbulence, suspension of sediments and locally elevated turbidity, etc.)

Evaluation of the temporal abundance of sculpins as reflected in their relative abundance among years showed that a decline occurred during 1976-1977, which was followed by a gradual recovery during 1978-1982 (Fig. 15). This decline and recovery was noted in both field and impingement collections as well as in diver observations of sculpins. No explanation can be offered for these changes in annual abundance. Of all fish observed by divers, sculpins were the most evenly distributed throughout the observational period (April-October). Unlike most other fish, sculpins were frequently observed in the study area during April-May and September-October. Although sculpins were impinged during most months, numbers of fish taken during April-May usually peaked at levels 10-fold higher than during other months (Thurber and Jude 1984, 1985). This was probably related to higher levels of activity and movement associated with spawning in riprap areas surrounding the intakes and subsequently, increased vulnerability to impingement. Elsewhere in the area, sculpins were found to move shoreward in early spring to spawn but generally avoided the warm inshore waters during summer (Tesar and Jude 1985).

Comparison of diving observations and impingement catches with the field distribution of sculpins underlines the attraction and concentration of fish in the riprap zone during periods (summer) when the overall abundance in the inshore area was low.

The uneven spatial distribution of sculpins reflects their preference for rough substrate and their attraction to the riprap. Sculpins were rarely observed in sand-bottom areas surrounding the riprap, although small numbers of fish were trawled and seined from these areas (Tesar and Jude 1985). Sculpins were also observed during other underwater studies in areas of natural rough substrate north and south of the Cook Plant (unpublished data, Great Lakes Research Division, Univ. Mich., Ann Arbor, Mich.).

All sculpins observed by divers were solitary. Most fish were adults, but juveniles were occasionally seen during late summer. Sculpins showed a distinctly nocturnal activity pattern which was reflected in the large number of fish observed during night transect swims (Appendix 2). During the day, fish remained hidden below the top layer of riprap and were less frequently observed. At night, they moved onto the upper surfaces of the stones where they remained active and alert. None was ever seen swimming off bottom, and only an occasional fish was sighted at night on top of the intake structures.

Burbot were commonly observed in the riprap area and were seen during 7 of the 10 study years. They were consistently the ninth-most abundant fish observed during all dives (Table 10) but were among the least frequently observed fish species seen during transect swims (Table 10). Similar to sculpins, burbot were relatively less abundant in field samples collected outside the riprap area than in impingement catches and diver observations

which sampled the population on the riprap (Fig. 16). These data suggest that burbot concentrated in the riprap area. The attraction was probably related to the increased protection that the more rugose substrate provided and not to some aspect of plant operation.

Diving observations revealed no temporal pattern in the seasonal inshore abundance or distribution of burbot, although field sampling and impingement catches indicated that the fish left the inshore area during summer months. Underwater observations of burbot revealed a clear pattern in their diel distribution. Nearly all fish were seen at night, and they remained out of sight during the day. As with sculpins, all burbot observed were solitary, alert, and active, although they could usually be approached and grasped by divers. They were always seen on the bottom and were usually entwined among the riprap.

Despite the relatively low abundance of burbot in the area, on one occasion a specimen was found lodged headdown inside a 7-cm diameter tube that had been suspended perpendicular to and 1 m off the bottom for three weeks to collect suspended sediment. This attested to the active exploration of the area by this particular species.

Burbot were never observed at reference stations, and their spatial distribution reflected their attraction and concentration in the riprap area. The relatively frequent impingement of burbot in relation to their low field abundance also reflected their concentration in the area. Construction divers working inside the intake and discharge pipes and plant forebay reported seeing burbot in high abundance relative to the riprap area (personal communication, A. Sebrechts, Sebrechts Inc., Bridgman, Michigan). Quite possibly,

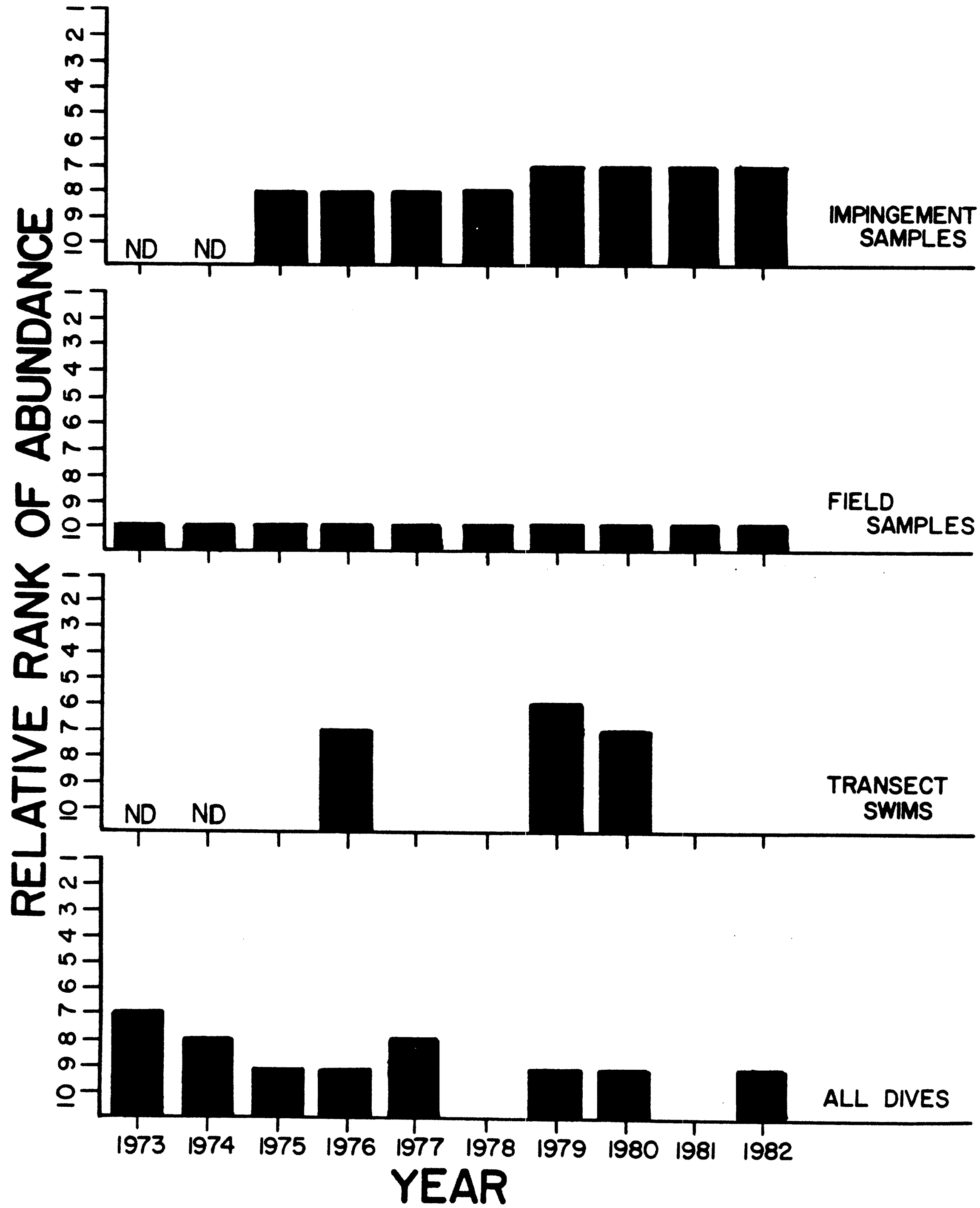


Fig. 16. Comparison of relative ranked abundance of burbot observed by divers during all dives (1973-1982) and transect swims (1975-1982), collected in standard series field samples (1973-1982), and impinged (1975-1982) at the D. C. Cook Nuclear Plant, southeastern Lake Michigan. Ordinate scale is inverted and extends from lowest to highest rank of relative abundance. Blanks indicate zero observations or catch; ND = no diving or sampling.

the fish were attracted to the dark interior of these structures, and ended up being impinged as a result.

Channel catfish and black bullheads were seen during two years of the study (Table 9), and a black bullhead was seen once during a night transect swim along the base of the south intake structure (Table 10). These fish were never observed at reference stations and were not seen in abundance on the reef. Most sightings occurred at night; fish were solitary and alert. No fish were seen swimming off bottom, and they were usually found in the interstices among the riprap rather than on top of it.

Demersal-Indifferent --

The species complex of diver-observed demersal fish that appeared to be indifferent to the in-lake structures or plant operation included johnny darter, white sucker, longnose sucker, quillback, and shorthead redhorse. The composite of diving observations, field studies, and impingement sampling indicated that these fish were distributed throughout the study area and did not appear to congregate in the riprap area.

Johnny darters were observed during all study years (Table 9) and during transect dives in all but the last year of diving (Table 10). They were typically about the fourth-most frequently observed species of fish. Although johnny darters were observed in abundance in the riprap area, they were also frequently seined in the beach zone and trawled at 6- and 9-m stations during field studies of fish (Tesar et al. 1985, Tesar and Jude 1985). Comparison of the relative ranked abundance of johnny darters showed that they were the sixth- to eighth-most frequently collected species in field sampling and the seventh- to ninth-most frequently impinged species (Fig. 17). The difference

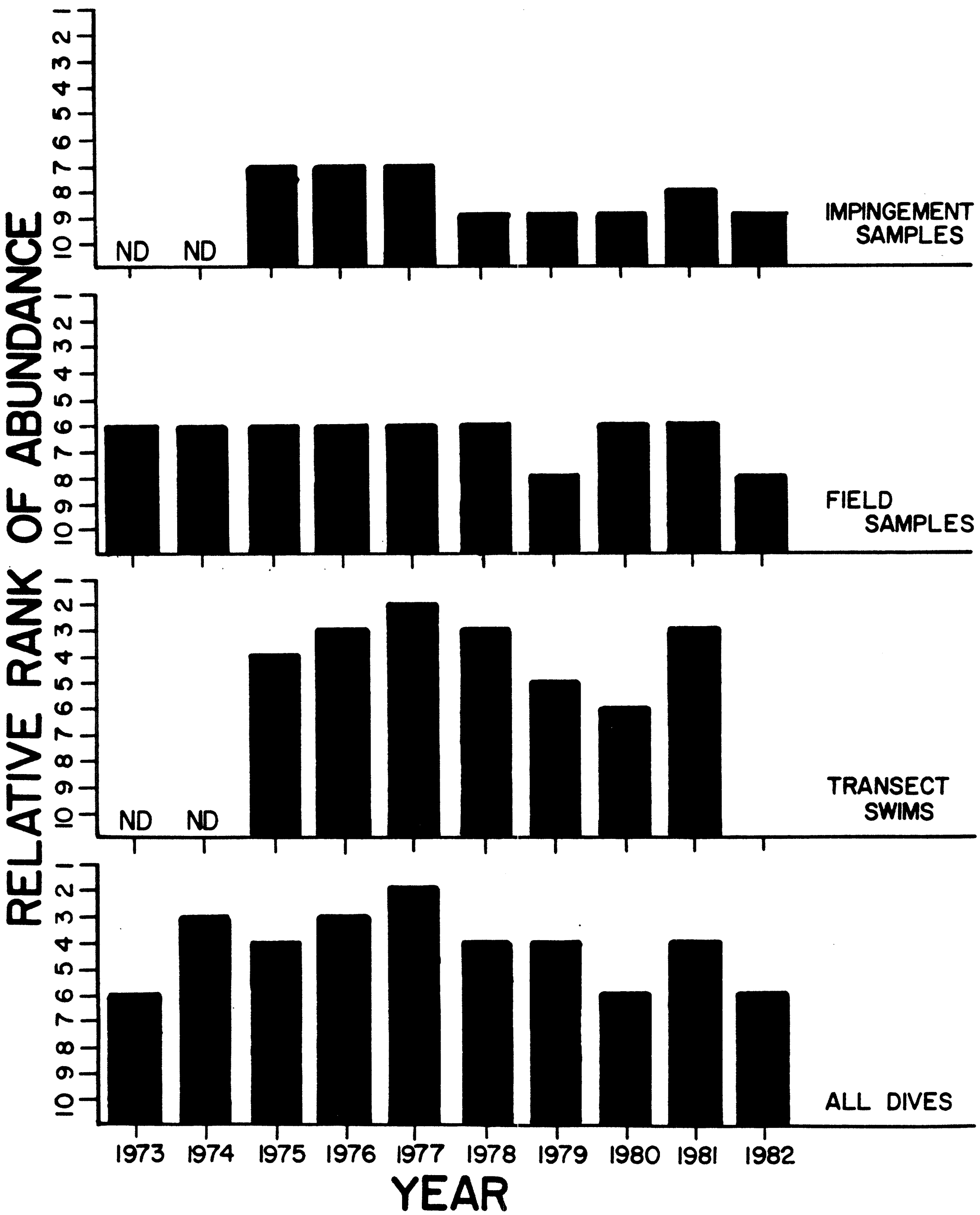


Fig. 17. Comparison of relative ranked abundance of johnny darters observed by divers during all dives (1973-1982) and transect swims (1975-1982), collected in standard series field samples (1973-1982), and impinged (1975-1982) at the D. C. Cook Nuclear Plant, southeastern Lake Michigan. Ordinate scale is inverted and extends from lowest to highest rank of relative abundance. Blanks indicate zero observations or catch; ND = no diving or sampling.

in absolute value of annual rank between these data sets never exceeded three and was often only one. These differences were probably not significant and did not suggest an unusually high rate of impingement of fish in relation to their general field abundance. Johnny darters were occasionally observed at dive study reference stations, although they were seen in far greater abundance on the riprap. The relative ranked abundance of johnny darters observed during transect swims and for all dives differed slightly in absolute value but followed nearly identical patterns in terms of annual variation. The close similarity in these patterns of abundance was attributed to the abundance, demersal behavior, and rather even distribution of johnny darters on the riprap. As a result, the small areas of riprap examined during transect swims served well as representative samples of the abundance of johnny darters.

Several patterns appeared in the temporal abundance and distribution of johnny darters. Diver observations and field and impingement catches suggested that the abundance of johnny darters relative to other species declined after 1977 and then fluctuated at lower levels during remaining years of study. The rebound in relative abundance was more apparent in field samples than in impingement samples or diver observations. This suggests that the decline was more pronounced in the riprap area relative to the surrounding area and that recovery to former levels of relative abundance was slower. Quantitative substantiation and explanation for a differential decline and recovery in abundance of johnny darter between the riprap and surrounding sand area are lacking.

Secondly, johnny darters were absent from the area during April and October, in contrast with their high abundance and widespread distribution

during warm-water months (May-September). Monthly peaks in numbers of fish observed, impinged, and collected in field samples often occurred in May and coincided with the spawning period for these fish (Fig. 8).

A final temporal pattern occurred in diel abundance. Although johnny darters were commonly seen during the day, numbers observed during transect swims were consistently higher at night (Appendix 2).

As noted earlier, although johnny darters were seen in much greater abundance at riprap stations than at reference stations, no overall patterns or differences in the spatial distribution of this species were supported among the three general studies (diving, field, impingement). While johnny darters may prefer rough substrate, particularly for spawning, they appear to be widely distributed inshore during spring, summer, and fall. The decline in rate of impingement of johnny darters during winter suggested that either the fish moved offshore, or their activity and susceptibility to impingement were lower during this period.

Nearly all johnny darters seen were adult fish, which were solitary, alert, and active during day and night. All fish were seen on the bottom and often rested on the upper surfaces of the riprap. Occasionally, a fish was observed on top of the intake structure.

White suckers were seen during 7 of the 10 study years and ranked as the ninth- or tenth-most frequently observed species of fish (Table 9). White suckers were never observed during transect swims, primarily because of their low abundance in the area. The relative ranked abundance of white suckers in field samples remained the same (seventh) for all but two years, when it declined by one rank (Fig. 18). Relative ranked abundance of white suckers in impingement samples fluctuated slightly but showed no strong patterns or

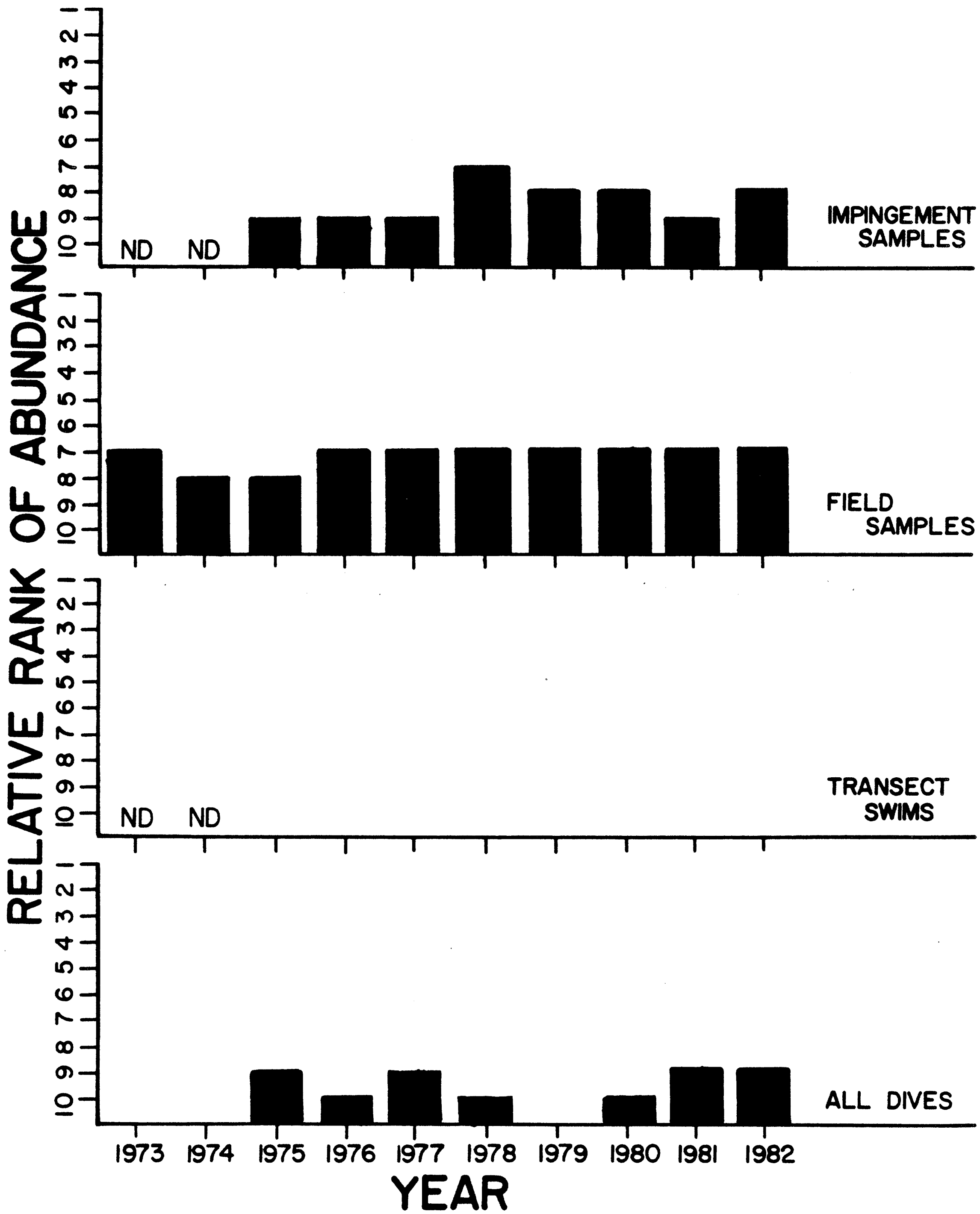


Fig. 18. Comparison of relative ranked abundance of white suckers observed by divers during all dives (1973-1982) and transect swims (1975-1982), collected in standard series field samples (1973-1982), and impinged (1975-1982) at the D. C. Cook Nuclear Plant, southeastern Lake Michigan. Ordinate scale is inverted and extends from lowest to highest rank of relative abundance. Blanks indicate zero observations or catch; ND = no diving or sampling.

trends. White suckers were observed consistently but in low numbers during most years of the underwater study.

A seasonal pattern in the temporal abundance of white suckers appeared in both underwater observations and field catch of this species. Fish were observed exclusively during May-August except on one occasion in September; most collected in field samples were also taken during May-August. Impingement of these fish tended to be greater in summer, but white suckers were impinged during most months and occasionally in relatively high numbers during winter. These data suggest that white suckers are generally more abundant inshore during warm-water months. It is possible that they move offshore during winter or some fish may have sought shelter from storms and ice inside the intake structures and pipes, thus accounting for the relatively high impingement during winter when field abundance was relatively low. White suckers were most often seen at night when they were solitary, alert, and active. Tesar and Jude (1985) found that this species moved shoreward at night in the study area.

Although white suckers were not observed at reference stations, there was no evidence that they were attracted to the plant structures or riprap or that operational factors affected their distribution. In fact, analysis of gill net data revealed that white suckers were significantly less abundant near the Cook Plant than at a reference station located 11 km south off Warren Dunes State Park, Michigan (Tesar and Jude 1985). These data indicate that white suckers may actually have avoided the Cook Plant area, perhaps in response to some operational factor such as discharge of heated water. A similar pattern of avoidance was noted at the J. H. Campbell Plant located north of the Cook Plant (Jude et al. 1982).

Longnose suckers were seen on several occasions during the study. Quillback and shorthead redhorse were each observed on one occasion. All of these fish were observed in the riprap zone, but attraction of these species to the area was not established.

The overall abundance and distribution of most fish observed by divers were influenced by several factors. One factor was the annual water temperature regime. Fish abundance, diversity, and levels of activity as observed by divers were generally highest during the warm-water months (May-September), with lowest levels of abundance, diversity, and activity occurring during April.

Abundance and diversity of fish observed by divers was generally higher at night than during the day. Part of this was because many fish were less wary at night and did not flee the area as divers approached. Also, many species of fish seen were nocturnal or showed no clear pattern of diel activity. Those species that were day-active often remained on bottom at night where they were readily visible to the divers.

Inshore turbulence associated with storms and surface waves appeared to cause many fish to retreat from the area. Offshore movements were most likely, but some fish (alewife and yellow perch) in the immediate vicinity of the Cook Plant appeared to seek shelter in the lee of the intake structures and were consequently more vulnerable to impingement during these periods. This response to storms was also documented by Lifton and Storr (1977).

Finally, for many of the species of fish observed during this underwater study, their onshore movements and peak abundance in the study area were often directly correlated with spawning activities. This was true for species that were attracted to the plant area for spawning substrate (e.g., yellow perch,

sculpins, johnny darter) or an operational factor (common carp) and for species that appeared indifferent to the presence or operation of the Cook plant (e.g., alewife, spottail shiner, rainbow smelt).

The spatial and temporal abundance of Lake Michigan fish found in the study area appears to be strongly influenced by environmental factors (substrate conditions, water temperature, storms, turbulence, ice, diel period) acting in concert with physiological needs of the fish (maturation, spawning, feeding, survival, growth) and the distribution of other aquatic biota (predators and prey). Our studies also indicate that the level of influence that these factors assert on fish abundance, distribution, and behavior changes as fish pass through various stages in their life history and physiological needs.

## ECOLOGY

Given some annual variation, most of the physical, chemical, and biological features of the study area remained basically unchanged during preoperational and operational phases of the Cook Plant (Rossmann 1986). Such factors included composition and configuration of surficial sediments, presence of lake currents and occasional occurrence of storms, annual water temperature regime, nutrient cycling, and the seasonal appearance of various animal populations in the area. These factors along with many others comprise the environment and dictate the growth and survival of plants and animals in the area. In most instances, these environmental interrelations and responses are complex and difficult to isolate or explain.

However, construction and operation of the Cook Plant resulted in some gross alterations in local environmental conditions which could be identified

and explored. The placement of plant structures and riprap in the lake created a small, isolated benthic environment that was atypical of the surrounding area. Subsequent operation of the plant which included withdrawal of water, circulation and warming of water inside the plant, and discharge of water back into the lake further affected both the benthic and pelagic environment in the immediate vicinity. Two basic themes underlie the initial discussion in this section: the first is an evaluation of the response of selected biota to the introduction of new habitat or sets of environmental conditions. The second theme is the response of these biota to habitat aging and changes in environmental conditions. The discussion is limited to observations and inferences that are derived from this underwater study.

The inshore physical environment in this region of the lake is variable in comparison with many other aquatic environments. Waves, currents, shifting surficial sediments, exposure to ice scour, and widely fluctuating water temperatures contribute to the set of conditions that stress plants and animals living in the area. The riprap and in-lake plant structures provided a stable substrate that afforded increased protection for mobile benthic organisms and a surface for attachment of sessile biota. This was reflected in the rapid colonization of this habitat by organisms not found in the surrounding environment, (e.g., periphyton and attached invertebrates) or which normally occurred in lesser abundance (e.g., snails, crayfish, and some fish).

Following placement of the structures and riprap in the lake, aging of their surfaces commenced and altered the conditions of this micro-environment. The structure surfaces first rusted and then accumulated bacterial slime, fine sediment, and particulate organic material. Bacterial slime grew on the

surface of the riprap while the holes and crevices, particularly those in its upper surfaces, trapped sediment and organic matter.

Periphyton rapidly colonized the exposed, upper surfaces of the structures and riprap, and Cladophora was often abundant. Snails appeared on the riprap within a year and attached invertebrates (Hydra, bryozoans, and sponges) colonized the substrate in the first few years. Crayfish also appeared on the reef within the first several years. Abundance of snails, crayfish, and some invertebrates peaked during the first three to five years and then declined to varying degrees. Snails disappeared completely from the riprap by the sixth year, and numbers of crayfish observed and impinged declined dramatically by the seventh year. The abundance of most attached invertebrates declined in later years of the study, but these organisms continued to be observed throughout the 10-yr study period. Interestingly, fluctuations occurred in the abundance of fish that were attracted to the area, but clear patterns or trends in their abundance were not evident. The reason for this may be that those factors which attracted the fish (e.g., shelter, circulating water, etc.) were not altered as much during the study as the micro-environment on the surface of the riprap. This in turn suggests that attraction of fish to the area may have been more a response to the physical configuration of the reef than to biological factors such as availability of prey (e.g., sculpin feeding on snails or perch feeding on crayfish).

In a stable environment, associated physical, chemical, and biological conditions often achieve some balance with each other. Patterns, trends, and random variations in these conditions are expected to occur during long periods of observation, but radical changes are either atypical (e.g., damage

or destruction of the structures) or at least predictable (upwellings). When existing habitat is altered or new habitat is introduced, the extant environmental conditions change and a new set of physical, chemical, and biological conditions begin to appear. Usually, some period of time is required to reform a stable and relatively predictable balance with this new set of conditions. The response of individual organisms to these environmental changes varies but is eventually reflected in population abundance and diversity. Populations may increase or decrease in numbers, and the rate at which this occurs may also vary. However, several basic patterns are known, and some occurred at the Cook Plant.

One pattern, shown by snails at the Cook Plant, is where population density follows a J-shaped curve over time. Initially, a positive acceleration phase occurs, followed by a logarithmic growth phase. Eventually, population density peaks and is then followed by a logarithmic decrease in population density and later, a negative acceleration phase (Knight 1965). Colonization, rapid population increase, peak abundance, and population decline of snails took place within a 4-yr period; over the next two years the population trailed off into extinction on the reef. The primary factor which initially encouraged population growth was most likely the appearance of clean, stable substrate. The major factor which eventually caused the extinction of snails on the reef may have been the accumulation of a thick coating of material (sediment, organic detritus, and algae) on the surface of the substrate. This material may have interfered with snail movement, ventilation, or incubation of eggs attached to the substrate. Changes may also have occurred in the composition of the detrital material upon which snails fed.

A second population density curve which develops in response to changing environmental conditions is the sigmoid curve. In this instance, the ascending limb and peak of the curve are followed by a series of oscillations which may be cyclic or nonperiodic and show trends and patterns or totally random changes in population abundance over time. Attached invertebrates and crayfish followed this general form of population density curve. Given time and eventual stabilization of environmental conditions on the reef, the population density curves of these organisms might eventually flatten or show some periodicity or trend. But the duration and intensity of sampling conducted during this study were insufficient to reveal such features in these population curves. The seasonal growth of *Cladophora* followed a variation of this curve where the length and density of the alga showed cyclic fluctuations according to season (maximum in summer, minimum in winter). However, no long-term trend superimposed on these cyclic oscillations was identified during the study.

Changes in surficial substrate conditions suspected to have affected snails probably also affected attached invertebrates and crayfish. Evidence indicated that *Cladophora* may have had a direct effect on these animals. In studies of artificial substrates placed on the Cook Plant riprap, Lauritsen and White (1981) found that *Cladophora* increased space available for clinging invertebrates such as Naididae, Oligochaeta, water mites, and amphipods. With the disappearance of most *Cladophora* in the fall, the total number of benthic invertebrates decreased, and filter feeders dominated the fauna. Prince et al. (1975) found that at Smith Mountain Lake, Virginia, crayfish were most abundant in areas of luxuriant *Cladophora* growth and absent from areas of the reef with little or no *Cladophora* growth. These observations

combined with those of the present study (see Free-living Macroinvertebrates) suggest that a direct relationship exists between the presence of Cladophora (or factors which promote growth of the alga) and the abundance of invertebrates at the Cook Plant. The population growth of snails may have been repressed by luxuriant Cladophora growth; whereas, the population growth of crayfish may have been enhanced. Attached invertebrates may have had to compete with the alga for substrate, and some of the aquatic insect larvae observed during the study may have fed on organisms living in association with Cladophora.

Another population density curve is asymptotic in shape. Unlike the J-shaped curve, no clear peak density is achieved but rather an asymptotic or flat, linear phase is established. Some possible examples of this curve were the population densities of yellow perch, sculpin, johnny darter, and burbot that were attracted to the rough substrate. Unfortunately, diving was not conducted before and immediately after placement of the substrate in the lake. Therefore, the initial increase in density which occurred as fish located and colonized the area was not recorded and the ascending limb of the curve was not reflected in the data. However, the relative ranked abundance of many of these fish underwent only minor fluctuations following colonization, and the actual abundance of these reef fish may have stabilized. As noted earlier, the attraction of these fish to the reef may have been more a response to its gross physical configuration and stability which remained nearly unchanged during the study, than to reef organisms (algae or invertebrates) that served as prey, or to micro-environmental conditions on the surface of the riprap. Interestingly, lake trout, which appear to have extremely specific requirements regarding spawning-substrate conditions, were never found to

utilize the Cook Reef for spawning; whereas, other fish (yellow perch, slimy sculpin, johnny darter, spottail shiner, and alewife) with less stringent spawning-substrate requirements spawned extensively on the reef. In contrast, lake trout did spawn on the newly-placed large riprap at the Campbell Plant (Jude et al. 1981b).

The population density curves of periphytic algae at the Cook Plant reef followed a pattern typical for colonial algae but unique in comparison with curves previously discussed. In general, abundance of individual algal forms peaked soon after colonization and then decreased slowly, thus defining asymmetric population density curves that were skewed to the right. However, as individual population densities decreased and more stability was attained, total diversity of forms increased almost linearly throughout the study. These opposing processes may have been the result of aging and increased stability of surficial substrate conditions acting in concert with the large number of rare forms present in the lake.

Most organisms studied during this investigation exhibited both temporal and spatial variation in their abundance and distribution. The three most obvious environmental effects were substrate conditions, water temperature, and photic conditions. Pronounced effects of substrate were found on the distribution of periphyton, attached invertebrates, snails, and crayfish and on the distribution and spawning of some fish. For all animals studied, presence of stable, rugose substrate attracted and concentrated biota that were less abundant in the surrounding environment of flat, exposed, shifting-sand bottom. Most organisms not attracted to the riprap zone (e.g., pelagic fish) were distributed in the area in a manner similar to that of the surrounding environment. However, the faunal distributions of some organisms

that would undoubtedly have been reduced by the presence of hard substrate, such as those of burrowing invertebrates, including sphaeriid clams or worms, were not studied.

Although short-term fluctuations in water temperature, such as upwellings, were encountered, their effects on the abundance and distribution of local biota were difficult to discern through diver observations. However, seasonal changes in water temperature had obvious effects on both plants and animals. In general, abundance and diversity of most organisms observed by divers were far greater during months of warm water than during early spring (April) or late fall (October). Part of this reduction was likely the result of reduced metabolic activity and movements as a function of lower water temperatures. But, frequent storm-generated turbulence and scouring of the bottom by ice made the inshore area considerably more inhospitable during the cold-weather period of the year.

The diel distribution of some animals was a direct result of phototrophic responses. Crayfish were distinctly more active at night as were sculpin and YOY alewives. Yellow perch and common carp were active during the day and inactive at night. While abundance of adult alewives appeared unaffected by photoperiod, schooling was a distinctly daytime activity. In general, most fish were less alert and more approachable by divers at night than during the day. Also, orientation of fish to the structures and riprap was often clearly obvious during the day and obscure or absent at night.

Finally, a distinct process of colonization and succession of biota on the Cook Plant structures and riprap was documented during this study. Although specific population density curves have been discussed, the overall pattern was one of initial location of habitat by extant biota, explosive

population growth which peaked during the first few years of the reef's existence, and a decline in population abundance to lower levels of fluctuating population abundance or extinction. This general pattern was most strikingly exhibited by sessile biota, perhaps because they were more directly affected by changes in substrate conditions than were motile organisms such as fish. These changes probably included shifts in micro-habitat conditions such as circulation of water and exchange of gases and nutrients at the substrate/water interface. The physical occlusion of the substrate surface, pores, cracks, and interstices by an accumulation of algae, sediment, and organic detritus probably influenced these micro-habitat conditions and dictated the response of organisms to that habitat.

Generally, artificial reefs are used throughout the world to increase local biological productivity (Rutecki et al. 1985). Such increases are achieved by expanding the variety and abundance of habitat available to biota. These conditions favor the survival and growth of individual organisms and promote local population increases. The Cook Plant structures and riprap have provided just such an environment which through its physical presence and modification of extant environmental conditions acting in combination with effects of plant operation have had a distinct impact on the local ecology. From the standpoint of diver-observed effects, this impact appears limited almost exclusively to the reef itself and has not influenced the ecology of the surrounding area to any noticeable extent.

## PLANT EFFECTS

### Physical Presence

The physical presence of Cook Plant in-lake structures and riprap

appeared to have several effects on the local environment that were not related to plant operation (e.g., circulation or discharge of heated water). These effects were generally related to an expansion of habitat which provided increased substrate for attachment, shelter, or reproduction of biota.

The structures and riprap provided stable substrate for the attachment and growth of periphytic algae and attached invertebrates including Hydra, bryozoans, and freshwater sponges. These animals were not found on shifting-sand substrate in the surrounding area.

Snails were attracted to the clean, stable substrate that provided a surface on which they could move about and lay their eggs. Crayfish may have fed on Cladophora or other periphyton attached to the riprap but also used the interstices among the stones for shelter and protection.

Several species of fish were attracted to the structures and riprap. Yellow perch congregated in the area in the late spring and remained more concentrated in the riprap zone than the surrounding area throughout the summer. Although alewives did not show any particular attraction to the area based on diver observations, impingement records indicated that fish clustered near the structure during storms and were thereby more vulnerable to entrapment (Thurber and Jude 1984, 1985). Demersal fish including sculpins, burbot, johnny darter, black bullheads, and catfish were attracted to the riprap probably as a result of their cryptozoic behavior. In all cases, the presence of the structures and riprap increased the amount of protected habitat available to these fish. Therefore, strictly from the standpoint of their physical presence, the structures and riprap enhanced and expanded local populations of some fish species in a manner that would not have occurred in the absence of this habitat. However, this enhancement must be balanced

against the operation of the plant which often contributed to mortality of fish occurring in the area.

The riprap served as spawning substrate for yellow perch, slimy sculpin, and johnny darter, and through this process may have enhanced the growth of local populations of these fish. Spottail shiners were observed to spawn on periphyton growing on top of the south intake structure, which provided an additional but probably insignificant amount of spawning habitat.

In overview, the physical presence of in-lake plant structures and riprap created an atypical, more sheltered, and more diverse habitat as compared to the surrounding area. These factors served to attract and concentrate biota which normally would be absent from the area or occur in considerably reduced numbers. In most instances, the presence of this habitat enhanced local populations of some plants and animals, while others (e.g., those of burrowing animals) were likely reduced. But, the attraction and enhancement of these populations must be balanced against their increased vulnerability to operational effects of the Cook Plant and plant-induced mortality.

Operational Effects

The entrainment of organisms during intake of plant cooling water and discharge of heated water and currents associated with the withdrawal and discharge of water were the major effects of plant operation that were noted by divers. Some of the physical impacts from plant operation have already been described and are summarized here. A shallow surface layer of warm water was occasionally encountered by divers at reference stations closest to the discharge structures. Warm water was also encountered when diving in the discharge area during one-unit plant operation. Elevated turbidity was occasion-

ally encountered at the north reference station nearest the plant, and on one dive, debris was flushed from the north discharge during cleaning of the plant forebay. Intake and discharge of water modified lake currents and waves in the immediate vicinity of the plant. We observed changes in ripple mark patterns on the bottom, encountered eddy currents at the discharge, and detected water masses of clearly differing temperature and transparency in the stratified intake water. Although the riprap trapped sediment and organic debris, some of these materials were re-suspended by plant-generated water currents.

Although the pelagic life stages of attached organisms were vulnerable to entrainment and possible plant-induced mortality, sessile adult organisms were considerably less susceptible to operational effects of the plant. Diver observations revealed that portions of the intake structures most directly exposed to intake water currents often supported the most luxuriant periphyton growth.

Crayfish were attracted to the riprap. However, intake currents strong enough to dislodge these animals from the substrate and result in their subsequent impingement in the plant were never encountered. Crayfish, which show pronounced negative phototatic behavior (Pennak 1953), most likely were attracted to the dark interior of the intake structures and pipes and eventually entered or were entrained into the the plant forebay and impinged on the traveling screens. The same process may have occurred for sculpins which concentrated in the riprap area; sculpins are also nocturnally active.

Diver-observed effects of plant operation on fish were limited to attraction of common carp to the heated discharge water and a general responsiveness of some species to currents at the intake structures. Although common carp spawned in the warm water as evidenced by the concentration of newly hatched

larvae at sampling stations nearest the thermal plume (Bimber et al. 1984), they may have been attracted to the plume for other reasons. No evidence was compiled to indicate that common carp would have been attracted to the area strictly in response to the physical presence of plant structures or riprap. Several species of fish, including yellow perch, alewives, and spottail shiners, were observed to exhibit positive rheotaxis and some position-holding in the area of strong intake currents. On occasion, some of these fish were observed to selectively congregate at various locations around the intake where the incoming water was warmer or less turbid than at other points. Cook Plant impingement records and other studies suggest that both alewives and yellow perch may have concentrated near the intake structures during storms and periods of extreme inshore turbulence, perhaps in search of shelter in the lee of the structures (Lifton and Storr 1977; Thurber and Jude 1984, 1985). Such concentrations, combined with the increased activity of fish during storms and possible disorienting effects of extreme turbulence, may have resulted in increased impingement of fish during and immediately following severe inshore turbulence.

Pelagic fish, including juvenile and adult alewife, spottail shiner, and yellow perch, were observed to swim in and out of the intake structures. This observation suggests that water intake currents outside the structures and at many points within the structures were not so strong as to over-power the fish. Rough measurements of current speed made by divers at the intake screens of the structures by timing the transport of suspended material along a measured distance indicated that intake currents at the screens were usually less than 0.5 m/sec. During seven-pump plant operation, currents at the intake screens occasionally approached 1 m/sec at points along the structure

which faced directly into the oncoming lake current. Commercial divers repairing the intake structures reported that there were specific locations within the structures where intake currents would suddenly increase (personal communication, A. Sebrechts, Sebrechts Inc., Bridgman, Mich.). These locations varied with the number of pumps operating, direction and speed of lake currents and surface waves, and eddy currents caused by recirculation of discharge water.

Review of fish swimming performance, summarized by Hocutt and Edinger (1980), indicates that water velocity at the Cook Plant intake screens is considerably less than the "burst" swimming speeds of most pelagic and juvenile fish found in the study area and does not exceed the "sustained" swimming speed for species such as alewife and yellow perch. They also reported that alewife demonstrate a countercurrent orientation in streams and prefer high velocity flow; whereas, yellow perch are inconsistent in their orientation to current.

We theorize that at the Cook Plant most fish voluntarily enter the structure and then may be unexpectedly subjected to strong currents occurring at varying locations within the structure. Upon entering the structure and suddenly encountering these currents, many fish probably retreat to areas of reduced current within or outside the structure; this scenario may be repeated many times before the fish eventually leave the area or are entrapped. Intake currents inside the pipes may approach 1.8 m/sec (6 ft/sec) during seven-pump operation, which would be 10 body lengths/sec for a 180 mm fish. Based on fish swimming performances cited in Hocutt and Edinger (1980), this value (10 lengths/sec) probably exceeds the "burst" swimming speed for many of the species of fish commonly impinged at the Cook Plant, particularly small fish.

Hocutt and Edinger noted that swimming performance is also related to the rate of velocity increase. Therefore, if a fish unexpectedly encounters a strong intake current inside the Cook Plant structure, escape may be difficult, particularly if the fish has been drawn through the structure and down into the intake pipe. If fish congregated near the structures for shelter during storms, the increase in turbulence could well disorient them or mask the intake current so that the fish might have increased difficulty sensing the sudden increases in intake current flow inside the structure. The end result would be that more fish would be entrained and impinged during storms, which was exactly what was observed at the Cook Plant.

Divers noted plant effects that were the result of the simple physical presence of the structures and riprap and some that were a function of plant operation. Most of these effects served to enhance local population densities of organisms attracted to the area. Negative effects (e.g., primarily entrainment and impingement) appeared to be limited more to plant operation than the physical presence of the structures and riprap in the lake and were inferred from other aspects of the Cook Plant studies. Barring a large change in the in-lake structure of the Cook Plant or its operation, future diver observation of additional major or significant ecological changes or plant impacts are not anticipated.

## SUMMARY

The physical, chemical, and biological features of the inshore environment surrounding the Cook Plant in-lake intake and discharge structures and riprap defined a harsh regime of environmental conditions relative to many other aquatic environments. A spectrum of flora and fauna existed in this

environment, but the abundance and distribution of most organisms appeared to be rather strictly dictated by the environmental conditions they encountered. The inshore Lake Michigan environment evaluated during this underwater study appeared relatively homogeneous, and considerable opportunity existed for the mobile life stages of flora and fauna to migrate and colonize new habitat.

Inshore surface waves may attain 4 m in the study area during intense storms, which contribute to the harsh nature of the environment. Effects of waves 0.5-1.0 m could be felt on the bottom by divers at depths less than 10 m. Lake currents were occasionally encountered by divers, but their effects were masked in areas where plant-generated currents could be felt. Both uni-directional and eddy currents were detectable throughout the water column within 100 m of the discharges; at stations more than 300 m from the discharges, weak plant-generated currents were noted occasionally, but lake currents appeared to predominate. Variable current speeds were encountered at the intake structures, but distinct differences often occurred at various points around the structures. Currents were strongest during seven-pump operation, and presence of warm water drawn into the shoreward sides of the structures suggested some recirculation of discharge water.

Thermal effects encountered during diving included seasonal large-scale changes in water temperature, short-term processes, including upwellings, and temperature stratification within the water column. A thin layer of naturally warmed water was occasionally found at the surface. Plant effects included presence of warm water near the discharge area and recirculation of discharge water.

The bottom profile of the inshore Lake Michigan environment was typically flat and unbroken. Sediments were composed of coarse- and fine-grained

shifting sand. Occasional "islands" of rock or clay substrate occurred in the inshore area of eastern Lake Michigan but were extremely limited in number and areal extent. These islands included habitat and environmental conditions more dissimilar to the surrounding area than to the physical conditions created by the Cook Plant in-lake structures and riprap.

Accumulations of surficial flocculent material typically ranged from 1 to 5 mm thick. Occasionally, large (10-m diameter, 1 m deep) depressions containing 20-40 mm of floc were encountered at reference stations. The riprap trapped sediment along with other inorganic and organic materials.

Water transparency ranged from less than 1 m to more than 6 m and was reduced during periods of inshore turbulence. High transparency was usually associated with extended periods (days to weeks) of stable weather and calm lake conditions. Transparency was occasionally reduced in the vicinity of the discharges and at specific points around the intake structure. These reductions were attributed to discharge turbulence and withdrawal of water from discrete water masses of differing turbidity.

Inorganic debris and organic detritus were more commonly observed in the riprap zone than at reference stations. This was believed to be primarily a function of the increased trapping action of the more rugose surface of the riprap. Inorganic trash accumulated as a result of plant construction and items discarded by fishermen angling over the reef. Organic debris was composed primarily of terrestrial plant material.

Periphyton colonized the structures and riprap within a year of placement in the lake. Seasonal growth patterns were clearly obvious, with algal length, density, and taxonomic diversity peaking during summer months. Most algae sloughed from the substrate during winter. <u>Cladophora</u> was abundant and

was suspected to have affected the abundance of other organisms on the reef, including attached or clinging invertebrates, crayfish, and possibly snails. No long-term pattern in length or luxuriance of periphyton growing on the plant structures or riprap was identified. However, taxonomic diversity and number of new forms recorded each year increased almost linearly throughout the study. These observations documented a pattern of colonization and succession that was typical for periphytic algae and also attested to the large number of rare forms present in the lake.

Attached invertebrates observed during the study included *Hydra*, bryozoans, and freshwater sponges. *Hydra* colonized the structure and riprap during its first year in the lake, as did bryozoans. Freshwater sponges appeared to require about two years to colonize the substrate. Peak abundance of these invertebrates on the reef occurred four to six years after placement in the lake. During the last several years of the study, abundance of *Hydra* and bryozoans declined, while numbers of sponge colonies continued to fluctuate and showed no particular pattern or trend. Riprap appeared to provide a more suitable substrate than did the metal structure, although large mats of *Hydra* were observed on the interior walls of the intake pipes and plant forebay.

Snails and crayfish colonized the riprap within its first year in the lake. Abundance of snails (*Physa*) peaked during the third year of the reef and then declined rapidly. No snails were observed during the last four years of the study. Extinction was believed to have been caused primarily by changes in the surface of the substrate as it aged and accumulated sediment, bacterial slime, periphyton, and organic detritus. Crayfish abundance peaked one year after that of snails. A rapid decline in abundance then occurred,

but unlike snails, crayfish continued to be observed in low numbers throughout the duration of the study. Decline in crayfish abundance was believed to be related to changes on the reef substrate surface operating in combination with initial overpopulation of the habitat. For both snails and crayfish, predation on eggs, juveniles, and adults by other crayfish and fish may have contributed to the decline in abundance of these invertebrates.

Several species of fish including yellow perch, slimy sculpin, and johnny darter spawned on the reef in preference to the surrounding sand-bottom area. Spottail shiners were observed to spawn over periphyton growing on top of an intake structure. Alewife eggs were seen in abundance but were about equally distributed over riprap and sand substrate, indicating that this species broadcasts its eggs at random without regard to substrate composition. Observation of fish eggs was limited to May-August, and spawning activity of the above species appeared to be concentrated in May-June.

Twenty-two taxa, encompassing 24 species of fish, were observed by divers during the study and were grouped according to frequency of observation. Frequently observed species included alewife, yellow perch, sculpins, johnny darter, and spottail shiner. All of these fish were seen at least once during every year of the study. Commonly observed species included trout-perch, common carp, rainbow smelt, burbot, and white sucker. These fish were seen during seven to nine years of the 10-year study. Uncommonly observed species included largemouth bass, lake trout, channel catfish, black bullhead, smallmouth bass, and longnose sucker. These fish were seen in more than one but less than half of the study years. Species that were rarely observed and were seen during only one year included emerald shiner, brown trout, quillback, walleye, unidentified coregonids, and shorthead redhorse.

Pelagic fish that appeared to be attracted to the in-lake presence or operation of the plant included yellow perch and common carp and possibly largemouth bass, smallmouth bass, and walleye. Pelagic species that appeared generally indifferent to the in-lake presence or operation of the plant included alewife, spottail shiner, trout-perch, rainbow smelt, lake trout, emerald shiner, brown trout, and coregonids. Demersal fish that appeared to be attracted to the in-lake presence or operation of the plant included slimy sculpin, burbot, channel catfish, and black bullhead. Demersal fish that appeared indifferent to the in-lake presence or operation of the plant included johnny darter, white sucker, longnose sucker, quillback, and shorthead redhorse.

Several generalizations related to fish behavior may be made based on this study. Species diversity and overall abundance of fish were higher during the warm-water months (June-August) than in the spring or late fall and higher at night than during the day. Day-active fish included yellow perch, common carp, and johnny darter. Nocturnally active fish included sculpins and burbot. Alewife, spottail shiner, trout-perch, and rainbow smelt showed no obvious pattern in diel activity. Daytime schooling was observed among adult alewife (500-1,000/school), yellow perch (10-50/school), and common carp (5-20/school), although aggregations tended to be loose and often included fish of widely differing sizes. Schooling among YOY fish was observed for alewife, yellow perch, and rainbow smelt. For all species that were active at night, swimming was more undirected and slower, and fish were more easily approached by divers than during the day.

Schools of YOY alewife were observed in September and October during most years. Schools of YOY yellow perch were occasionally seen in August.

Observation of these YOY fish coincided with their appearance inshore at this time of the year and was further documented in field and impingement catches.

Fish abundance and diversity were greater in the riprap area than in the surrounding area of sand substrate. Yellow perch, slimy sculpins, johnny darter, burbot, channel catfish, and black bullheads were probably attracted to the vertical relief and protection that the rugose substrate offered. Common carp appeared to be attracted to the warm-water discharge. Largemouth bass, smallmouth bass, and walleye were seen in close association with the structures and may have been attracted to the vertical relief that these objects presented. Alewives were seen in abundance in all of the study area but may have sought shelter near the structures during periods of inshore turbulence. Spottail shiners, rainbow smelt, and trout-perch did not appear attracted or repelled by the physical presence of the reef or operation of the plant. Excluding the operational effects of entrainment and impingement on fish at various life stages, the physical presence of the structures and riprap appeared to enhance fish populations by providing additional habitat for spawning, feeding, and protection from predation and harsh inshore lake conditions.

The seasonal abundance of fish observed by divers in the study area was often directly correlated with their spawning activities. This was true for species that were attracted to the plant area for spawning substrate (e.g., yellow perch, sculpins, johnny darter) or by an operational factor (common carp), as well as for species that appeared indifferent to the presence or operation of the Cook Plant (e.g., alewife, spottail shiner, rainbow smelt).

The spatial and temporal abundance of Lake Michigan fish found in the study area appeared to be strongly influenced by environmental factors

(substrate conditions, water temperature, storms, turbulence, ice, diel period) acting in concert with physiological needs of the fish (maturation, spawning, feeding, survival, growth) and presence of other lake biota (predators and prey). Our studies also indicated that the level of influence that these factors assert on fish abundance, distribution, and behavior changes as fish pass through various stages in their life history and physiological needs.

The Cook Plant structures and riprap have created habitat atypical of the surrounding environment. Through its physical presence and modification of extant environmental conditions acting in combination with effects of plant operation, it has had a distinct impact on the local ecology. Population increases for some organisms, including periphytic algae, attached and free-living invertebrates, and pelagic and demersal fish, have been achieved through the expansion of substrate to provide increased shelter and a more diversified habitat relative to the surrounding environment. Environmental conditions on the reef have favored the survival and growth of individual organisms and resulted in local population increases. From the standpoint of diver observations, effects of these changes appeared limited almost exclusively to the reef itself and have not influenced the ecology of the surrounding area to any noticeable extent.

Presence of the riprap served to enhance local population densities of organisms attracted to the area. The attraction and enhancement of these populations must be balanced against their increased vulnerability to operational effects of the Cook Plant and plant-induced mortality. Negative effects (e.g., primarily entrainment and impingement) appeared to be limited more to plant operation than the physical presence of the plant structures and

riprap in the lake and were inferred more from other components of the Cook Plant studies than from diver observations. Barring major modifications to the in-lake structures or operation of the Cook Plant, future diver observation of additional large or significant ecological changes or plant impacts are not anticipated.

## REFERENCES


Auer, N. A. (ed.) 1982. Identification of larval fishes of the Great Lakes basin with emphasis on the Lake Michigan drainage. Spec. Publ. No. 82-3. Great Lakes Fish. Comm., Ann Arbor, Mich. 744 pp.

Ayers, J. C., D. C. Chandler, G. H. Lauff, C. F. Powers, and E. B. Henson. 1958. Currents and water masses in Lake Michigan. Publ. No. 3. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich. 169 pp.

Barres, J., L. Feldt, W. Chang, and R. Rossmann. 1984. Entrainment of phytoplankton at the Donald C. Cook Nuclear Plant - 1980-1982. Part XXXII. Benton Harbor Power Plant Limnological Studies. Spec. Rep. No. 44. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich. 92 pp. plus microfiche.

Biener, W. E. 1982. Evaluation of an artificial reef placed in southeastern Lake Michigan: fish colonization. M.S. thesis. Mich. State Univ., East Lansing, Mich. 40 pp.

Bimber, D. L., M. Perrone, Jr., L. S. Noguchi, and D. J. Jude. 1984. Field distribution and entrainment of fish larvae and eggs at the Donald C. Cook Nuclear Power Plant, southeastern Lake Michigan, 1973-1979. Spec. Rep. No. 105, Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich. 320 pp.

Brown, E. H., Jr. 1968. Population characteristics and physical condition of alewives, Alosa pseudoharengus, in a massive dieoff in Lake Michigan, 1967. Tech. Rep. No. 13. Great Lakes Fish. Comm., Ann Arbor, Mich. 20 pp.

Cornelius, S. D. 1984. Macroinvertebrate colonization of the Muskegon freshwater reef. M.S. thesis. Mich. State Univ., East Lansing, Mich. 109 pp.

Davis, R. A., and D. F. R. McGeary. 1965. Stability in the nearshore bottom topography and sediment distribution, southeastern Lake Michigan. Pages 222-231 in Proc. 8th Conf. Great Lakes Res., Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich.

Dorr III, J. A. 1974. Underwater operations in southeastern Lake Michigan near the Donald C. Cook Nuclear Power Plant during 1973. Pages 465-475 in E. Seibel, and J. C. Ayers, eds. The biological, chemical and physical character of Lake Michigan in the vicinity of the Donald C. Cook Nuclear Plant. Spec. Rep. No. 51. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich.

Dorr III. J. A. 1982. Substrate and other environmental factors in reproduction of the yellow perch (Perca flavescens). Ph.D. thesis. Univ. Mich., Ann Arbor, Mich. 276 pp.

Dorr III, J. A., and D. J. Jude. 1980a. SCUBA assessment of abundance, spawning, and behavior of fishes in southeastern Lake Michigan near the Donald C. Cook Nuclear Plant, 1975-1978. Mich. Acad. 12:345-364.

Dorr III, J. A., and D. J. Jude. 1980b. Scuba observations in eastern Lake Michigan near Muskegon Harbor, 13-14 September 1979. Spec. Rep. No. 76. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich. 15 pp.

Dorr III, J. A., and T. J. Miller. 1975. Underwater operations in southeastern Lake Michigan near the Donald C. Cook Nuclear Plant during 1974. Part XXII. Benton Harbor Power Plant Limnological Studies. Spec. Rep. No. 44. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich. 32 pp.

Dorr III, J. A., D. V. O'Connor, N. R. Foster, and D. J. Jude. 1981a. Substrate conditions and abundance of lake trout eggs in a traditional spawning area in southeastern Lake Michigan. N. Amer. J. Fish. Mgt. 1:165-172.

Dorr III, J. A., D. J. Jude, G. R. Heufelder, S. A. Klinger, G. E. Noguchi, T. L. Rutecki, and P. J. Schneeberger. 1981b. Preliminary investigation of spawning habitat conditions and reproduction of lake trout in eastern Lake Michigan near Port Sheldon, Michigan. Pub. No. MICHU-SG-81-213. Mich. Sea Grant Prog., Univ. Mich., Ann Arbor, Mich. 22 pp.

ETA. 1980. Report on the characteristics of thermal discharge from D. C. Cook Units 1 & 2. Vol. I. Environmental Technical Assessment. Chicago, Illinois. 50 pp.

Hawley, E. F., and C. W. Judge. 1969. Characteristics of Lake Michigan bottom profiles and sediments from Lakeside, Michigan to Gary, Indiana. Pages 198-209 in Proc. 12th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res.

Hocutt, C. H., and J. E. Edinger. 1980. Fish behavior in flow fields. Pages 143-181 in C. H. Hocutt et al., eds. Power Plants: effects on fish and shellfish behavior. Acad. Press. New York, New York.

Hough, J. L. 1958. Geology of the Great Lakes. Univ. Ill. Press. Urbana, Ill. 313 pp.

Indiana & Michigan Power Company. 1975. Donald C. Cook Nuclear Plant Unit 1 environmental operating report, July 1, 1975 through December 31, 1975. American Electric Power Service Corporation. New York, New York. Unnum. pp.

Indiana & Michigan Power Company. 1976. Donald C. Cook Nuclear Plant Unit 1 environmental operating report, January 1, 1975 through June 30, 1975. American Electric Power Service Corporation. New York, New York. 26 pp. plus appendices.

Jude, D. J., and F. J. Tesar. 1985. Recent changes in the forage fish of Lake Michigan. Can. J. Fish. Aquat. Sci. 42:1154-1157.

Jude, D. J., B. A. Bachen, G. R. Heufelder, H. T. Tin, M. H. Winnell, F. J. Tesar, and J. A. Dorr III. 1978. Adult and juvenile fish, ichthyoplankton and benthos populations in the vicinity of the J. H. Campbell Power Plant, Eastern Lake Michigan, 1977. Spec. Rep. No. 65. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich. 639 pp.

Jude, D. J., F. J. Tesar, J. C. Tomlinson, T. J. Miller, N. J. Thurber, G. G. Godun, and J. A. Dorr III. 1979. Inshore Lake Michigan fish populations near the Donald C. Cook Nuclear Power Plant during preoperational years - 1973, 1974. Spec. Rep. No. 71. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich. 529 pp.

Jude, D. J., H. T. Tin, G. R. Heufelder, P. J. Schneeberger, C. P. Madenjian, T. L. Rutecki, P. J. Mansfield, N. A. Auer, and G. E. Noguchi. 1981a. Adult, juvenile and larval fish populations in the vicinity of the J. H. Campbell Power Plant, eastern Lake Michigan, 1977-1980. Spec. Rep. No. 86. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich. 364 pp.

Jude, D. J., S. A. Klinger, and M. D. Enk. 1981b. Evidence of natural reproduction by planted lake trout in Lake Michigan. J. Great Lakes Res. 7:57-61.

Jude, D. J., C. P. Madenjian, P. J. Schneeberger, H. T. Tin, P. J. Mansfield, T. L. Rutecki, G. E. Noguchi, and G. R. Heufelder. 1982. Adult, juvenile and larval fish populations in the vicinity of the J. H. Campbell Power Plant, 1981, with special reference to the effectiveness of wedge-wire intake screens in reducing entrainment and impingement of fish. Spec. Rep. No. 96. Great Lakes. Res. Div., Univ. Mich., Ann Arbor, Mich. 516 pp.

Knight, C. B. 1965. Basic concepts of ecology. The Macmillan Company, New York, New York. 468 pp.

Lauritsen, D. D., and D. S. White. 1981. Comparative studies of the zoobenthos of a natural and a man-made rocky habitat on the eastern shore of Lake Michigan. Spec. Rep. No. 74. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich. 65 pp.

Lifton, W. S., and J. F. Storr. 1977. The effect of environmental variables on fish impingement. Pages 299-311 _in_ L. D. Jensen, ed. Proceedings of the Fourth National Workshop on Entrainment and Impingement. Ecological Analysts, Inc., Melville, New York.

Miller, G. A. 1956. The magical number seven, plus or minus two: some limits on our capacity for processing information. Psych. Rev. 63:82-97.

Mortimer, C. H. 1975. Environmental status of the Lake Michigan region. Part 1, physical characteristics of Lake Michigan and its responses to applied forces. Environ. Cont. Tech. Earth Sci. Argonne Nat. Lab, Argonne, Ill. 121 pp.

Noguchi, L., D. Bimber, H. Tin, P. Mansfield, and D. Jude. 1985. Field distribution and entrainment of fish larvae and eggs at the Donald C. Cook Nuclear Power Plant, southeastern Lake Michigan, 1980-1982. Spec. Rep. No. 116, Great Lakes Res. Div., Univ. Mich, Ann Arbor, Mi. 251 pp.

Nursall, J. R. 1973. Some behavorial interactions of the spottail shiner (_Notropis hudsonius_), yellow perch (_Perca flavescens_), and northern pike (_Esox lucius_). J. Fish. Res. Board Can. 30:1161-1178.

Pennak, R. W. 1953. Fresh-water invertebrates of the United States. The Ronald Press Company, New York, New York. 769 pp.

Perrone, M. Jr., P. J. Schneeberger, and D. J. Jude. 1983. Distribution of larval yellow perch (Perca flavescens) in nearshore waters of southeastern Lake Michigan. J. Great Lakes Res. 9:517-522.

Prince, E. D., R. F. Raleigh, and R. V. Corning. 1975. Artificial reefs and centrarchid bass. Pages 498-505 in R. H. Stroud and H. Clepper, eds. Black bass biology and management. Sport Fish. Inst., Washington, D.C.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. 4th ed. Spec. Pub. No. 12. Amer. Fish. Soc., Bethesda, Maryland. 174 pp.

Rossmann, R. (ed.) 1986. Southeastern nearshore Lake Michigan: impact of the Donald C. Cook Nuclear Plant. Publication 22. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich. 440 pp.

Rossmann, R., and E. Seibel. 1977. Surficial sediment redistribution by wave energy: element-grain size relationships. J. Great Lakes Res. 3:258-262.

Rossmann, R., W. Chang, and J. Barres. 1982. Entrainment of phytoplankton at the Donald C. Cook Nuclear Plant - 1979. Part XXX. Benton Harbor Power Plant Limnological Studies. Spec. Rep. No. 44. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich. 98 pp.

Rutecki, T. L., P. J. Schneeberger, and D. J. Jude. 1983. Diver and underwater television observations of fish behavior in a Great Lakes Commercial trap net. J. Great Lakes Res. 9:359-364.

Rutecki, T. L., J. A. Dorr III, and D. J. Jude. 1985. Preliminary analysis of colonization and succession of selected algae, invertebrates, and fish on two artificial reefs in inshore southeastern Lake Michigan. Pages 459-489 in F. M. D'Itri, ed. Artificial reefs: marine and freshwater applications. Lewis Publishers, Inc., Chelsea, Mich.

Schneeberger, P. J. 1982. Observations and modeling of fish gilling in commercial trap net pots. M.S. thesis. Univ. Mich., Ann Arbor, Mich. 38 pp.

Schneeberger, P. J., T. L. Rutecki, and D. J. Jude. 1982. Gilling in trap-net pots and use of catch data to predict lake whitefish gilling rates. N. Amer. J. Fish. Mgt. 2:294-300.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Bull. 184. Fish. Res. Board. Can., Ottawa, Ont. 966 pp.

Seibel, E., R. E. Jensen, and C. T. Carlson. 1974. Surficial sediment distribution of the nearshore waters in southeastern Lake Michigan. Pages 369-432 in E. Seibel and J. C. Ayers, eds. The biological, chemical, and physical character of Lake Michigan in the vicinity of the Donald C. Cook Nuclear Plant. Spec. Rep. No. 51. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich.

Shaw, E. 1975. Schooling fishes. Amer. Sci. 66:166-175.

Tesar, F. J., and D. J. Jude. 1985. Adult and juvenile fish populations of inshore southeastern Lake Michigan near the Cook Nuclear Power Plant during 1973-82. Spec. Rep. No. 106. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich. 94 pp.

Tesar, F. J., D. Einhouse, H. T. Tin, D. L. Bimber, and D. J. Jude. 1985. Adult and juvenile fish populations near the D. C. Cook Nuclear Power Plant, southeastern Lake Michigan, during preoperational (1973-74) and operational (1975-79) years. Spec. Rep. No. 109. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich. 341 pp.

Thurber, N., and D. J. Jude. 1984. Impingement losses at the D. C. Cook Nuclear Plant during 1975-1979 with a discussion of factors responsible and relationships to field catches. Spec. Rep. No. 104. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich. 24 pp. plus 75-page appendix.

Thurber, N., and D. J. Jude. 1985. Impingement losses at the D. C. Cook Nuclear Power Plant during 1975-1982 with a discussion of factors responsible and possible impact on local populations. Spec. Rep. No. 115, Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mi. 158 pp.

U.S. Atomic Energy Commission. 1975. Environmental technical specifications for the Donald C. Cook Nuclear Plant Units 1 and 2, Berrien County, Michigan. Docket Nos. 50-315 and 50-316. Directorate of Licensing, Washington, D.C.

Wells, L. 1973. Distribution of fish fry in nearshore waters of southeastern and east-central Lake Michigan, May-August 1972. Admin. Rep. Great Lakes Fish. Lab., Ann Arbor, Mich. 24 pp.

Wetzel, R. G. 1975. Limnology. W. B. Saunders Company, Philadelphia, Penn. 743 pp.

Winnell, M. H. 1984. Ecology of the zoobenthos of southeastern Lake Michigan near the D. C. Cook Nuclear Power Plant. Part 5: Malacostraca (Amphipoda, Mysidacea, Isopoda, and Decapoda). Spec. Rep. No. 99. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich. 94 pp.

Winnell, M. H., and D. J. Jude. 1981. Spatial and temporal distribution of benthic macroinvertebrates and sediments collected in the vicinity of the J. H. Campbell Plant, eastern Lake Michigan, 1980. Spec. Rep. No. 87. Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich. 110 pp.

Appendix 1. Summary of observations made during dives on riprap substrate surrounding the D. C. Cook Nuclear Plant intake and discharge structures in southeastern Lake Michigan, 1973-1982.

| Category | Apr | May | Jun | Jul | Aug | Sep | Oct |
|---|---|---|---|---|---|---|---|
| | | | | 1973 | | | |
| No. of dives[1] | | | 3 | | 3 | 3 | |
| Periphyton[2] | | | | | | | |
| Structure | | | 3.7 | | 3.7 | 3.2 | |
| Riprap | | | 0.5 | | 2.0 | 2.5 | |
| Invertebrates[3] | | | | | | | |
| Crayfish | | | 1 | | 1 | 1 | |
| Snails | | | | | >100 | 26 | |
| *Hydra* | | | | | | X | |
| Bryozoans | | | | | | | |
| Sponge | | | | | | | |
| Other | | | | | | | |
| Fish[4] | | | | | | | |
| YP | | | 95 | | | | |
| JD | | | 12 | | 3 | | |
| SS | | | 10 | | 5 | 6 | |
| TP | | | 50 | | | | |
| SP | | | >1,000 | | | | |
| AL | | | >200 | | 50 | | |
| BR | | | | | | | |
| CC | | | | | | | |
| CP | | | | | | | |
| ES | | | | | | | |
| BB | | | | | | | |
| LT | | | | | | | |
| WS | | | | | | | |
| SB | | | | | | | |
| SM | | | | | | | |
| LB | | | | | | | |
| BT | | | | | | | |
| LS | | | | | | | |
| QB | | | | | | | |
| SR | | | | | | | |
| XC | | | | | | | |
| WL | | | | | | | |
| Fish eggs[5] | | | | | | | |
| Riprap | | | SP | | | | |
| Sand | | | | | | | |

(Continued).

Appendix 1. Continued.

| Category | Apr | May | Jun | Jul | Aug | Sep | Oct |
|---|---|---|---|---|---|---|---|
| | | | | 1974 | | | |
| No. of dives[1] | 2 | 3 | 3 | | | 1 | 2 |
| Periphyton[2] | | | | | | | |
| Structure | 0 | 3.8 | 7.5 | | | | 3.0 |
| Riprap | 0 | 0.5 | 1.0 | | | | 1.3 |
| Invertebrates[3] | | | | | | | |
| Crayfish | 1 | 5 | 30 | | | 50 | 1 |
| Snails | 0 | 100 | >100 | | | 75 | >100 |
| *Hydra* | | | | | | | |
| Bryozoans | | | | | | | X |
| Sponge | | | | | | | |
| Other | | | | | | | P |
| Fish[4] | | | | | | | |
| YP | | 25 | 45 | | | | |
| JD | | 39 | 60 | | | 2 | |
| SS | | >100 | 2 | | | 75 | 72 |
| TP | | | 50 | | | | |
| SP | | | >100 | | | | |
| AL | | | 35 | | | | 2 |
| BR | | 1 | | | | | |
| CC | | 1 | | | | | |
| CP | | 1* | 1 | | | | |
| ES | | 1 | | | | | |
| BB | | 1 | | | | | |
| LT | | | | | | | 1 |
| WS | | | | | | | |
| SB | | | | | | | |
| SM | | | | | | | |
| LB | | | | | | | |
| BT | | | | | | | |
| LS | | | | | | | |
| QB | | | | | | | |
| SR | | | | | | | |
| XC | | | | | | | |
| WL | | | | | | | |
| Fish eggs[5] | | | | | | | |
| Riprap | | SS | SP | | | | |
| Sand | | | | AL | | | |

(Continued).

Appendix 1. Continued.

| Category | Apr | May | Jun | Jul | Aug | Sep | Oct |
|---|---|---|---|---|---|---|---|
| | | | | 1975 | | | |
| No. of dives[1] | 1 | 2 | 3 | 3 | 3 | 3 | 3 |
| Periphyton[2] | | | | | | | |
| Structure | 0 | 2.5 | 13.8 | 12.5 | 7.5 | 5.0 | 1.0 |
| Riprap | 0.5 | 1.0 | 12.5 | 5.0 | 4.0 | 5.0 | 1.0 |
| Invertebrates[3] | | | | | | | |
| Crayfish | | 5 | 37 | 95 | 89 | 103 | 70 |
| Snails | | >1,000 | | 30 | 28 | 7 | |
| Hydra | | | | | | | |
| Bryozoans | | | | | | | |
| Sponge | | | | | | X | X |
| Other | | | | | | | |
| Fish[4] | | | | | | | |
| YP | | 5 | >100 | 67 | 54 | | |
| JD | | 4 | 4 | 62 | >133 | 15 | |
| SS | | 19 | >100 | >100 | >128 | 51 | 32 |
| TP | | | 1 | 60 | | | |
| SP | | | >100 | | | | |
| AL | | 4 | >1,000 | >1,000 | >1,000 | >1,000 | >1,000 |
| BR | | | | 1 | | | |
| CC | | | | | | | |
| CP | | | 1 | 3+1* | 2 | 2 | |
| ES | | | | | | | |
| BB | | | | | | | |
| LT | | | | | | | |
| WS | | | | 1 | | | |
| SB | | | | 1 | | | |
| SM | | | | | 2 | | |
| LB | | | | | | 1 | |
| BT | | | | | | | |
| LS | | | | | | | |
| QB | | | | | | | |
| SR | | | | | | | |
| XC | | | | | | | |
| WL | | | | | | | |
| Fish eggs[5] | | | | | | | |
| Riprap | | AL,SP,YP | AL | | | | |
| Sand | | | | | | | |

(Continued).

Appendix 1. Continued.

| Category | Apr | May | Jun | Jul | Aug | Sep | Oct |
|---|---|---|---|---|---|---|---|
| | | | | 1976 | | | |
| No. of dives[1] | 3 | 3 | 3 | 3 | 3 | 3 | 1 |
| Periphyton[2] | | | | | | | |
| Structure | 0 | 0 | 2.5 | 11.5 | 10.0 | 6.3 | 5.0 |
| Riprap | 1.2 | 1.2 | 1.5 | 2.5 | 1.0 | 0.5 | 0.5 |
| Invertebrates[3] | | | | | | | |
| Crayfish | 3 | 18 | 27 | >216 | >382 | >134 | 5 |
| Snails | | 2 | | 1 | | | |
| Hydra | | | | | | | |
| Bryozoans | | | X | | | X | X |
| Sponge | | | | | X | X | X |
| Other | T | E | | N | | | |
| Fish[4] | | | | | | | |
| YP | 2 | 1 | 107 | 13 | 8 | 1 | |
| JD | | >119 | 24 | 11 | | | |
| SS | 13 | 79 | 89 | 59 | 135 | 9 | 8 |
| TP | | | 1 | | 3 | | |
| SP | | 2 | 2 | 7 | 2 | 3 | |
| AL | 1 | 2 | >1,000 | >100 | >243 | >1,000 | 108 |
| BR | | | 1 | | 1 | | |
| CC | | | | | | | |
| CP | | 1 | 2 | 8 | 7 | 30 | |
| ES | | | | | | | |
| BB | | | | | | | |
| LT | | | | | | | |
| WS | | | | 1 | | | |
| SB | | | | 1 | | | |
| SM | 1 | 1 | | | 1 | | |
| LB | | | | | | | |
| BT | | | | | | | |
| LS | | | | | | | |
| QB | | | | | | | |
| SR | | | | | | | |
| XC | | | | | | | |
| WL | | | | | | | |
| Fish eggs[5] | | | | | | | |
| Riprap | | | SP,AL | AL | AL | | |
| Sand | | | AL | AL | | | |

(Continued).

Appendix 1. Continued.

| Category | Apr | May | Jun | Jul | Aug | Sep | Oct |
|---|---|---|---|---|---|---|---|
| | | | | 1977 | | | |
| No. of dives[1] | 3 | 3 | 3 | 3 | 3 | 2 | |
| Periphyton[2] | | | | | | | |
| Structure | 0.5 | 0.5 | 1.5 | 1.8 | 3.0 | 1.5 | |
| Riprap | 0.4 | 1.0 | 1.0 | 1.2 | 1.5 | 0.3 | |
| Invertebrates[3] | | | | | | | |
| Crayfish | >225 | 122 | >125 | >298 | >151 | 15 | |
| Snails | | | | 1 | | | |
| Hydra | | | | | | | |
| Bryozoans | | | | | X | | |
| Sponge | X | X | X | X | X | X | |
| Other | | | | | | | |
| Fish[4] | | | | | | | |
| YP | 7 | 43 | 14 | 187 | 13 | | |
| JD | 1 | 200 | 50 | 28 | 11 | | |
| SS | 21 | 42 | 8 | | 7 | | |
| TP | | | | | | | |
| SP | | 5 | | | | | |
| AL | 1 | 39 | >1,000 | 16 | >1,000 | 1 | |
| BR | | 1 | | | | | |
| CC | | | | | | | |
| CP | 5 | 13 | 31 | 14 | | | |
| ES | | | | | | | |
| BB | | | | | | | |
| LT | | | | | | | |
| WS | | 1 | | | | | |
| SB | | | | | | | |
| SM | 2 | | | | >102 | | |
| LB | | 2 | | | | | |
| BT | | | | | | | |
| LS | | | | | | | |
| QB | | | | | | | |
| SR | | | | | | | |
| XC | | | | | | | |
| WL | | | | | | | |
| Fish eggs[5] | | | | | | | |
| Riprap | | JD,YP | JD,YP,AL | AL | | | |
| Sand | | | AL | AL | | | |

(Continued).

Appendix 1. Continued.

| Category | Apr | May | Jun | Jul | Aug | Sep | Oct |
|---|---|---|---|---|---|---|---|
| | | | | 1978 | | | |
| No. of dives[1] | 2 | 3 | 3 | 3 | 3 | 3 | 2 |
| Periphyton[2] | | | | | | | |
| Structure | 0.3 | 0.1 | 7.5 | 10.0 | 3.0 | 2.0 | 1.7 |
| Riprap | 0 | 1.0 | 3.5 | 8.0 | 7.5 | 2.5 | 2.0 |
| Invertebrates[3] | | | | | | | |
| Crayfish | 5 | 7 | | 1 | 11 | 47 | |
| Snails | 1 | 1 | | | | | |
| *Hydra* | | | | | | | X |
| Bryozoans | | | | | X | | |
| Sponge | | | X | | X | X | X |
| Other | | M,C | | | | | |
| Fish[4] | | | | | | | |
| YP | | 11 | 13 | 25 | 1 | | |
| JD | | 7 | 6 | 15 | 5 | 5 | |
| SS | 5 | 14 | | | 8 | 10 | 1 |
| TP | | | 8 | | | 3 | |
| SP | | | 2 | | 11 | 2 | |
| AL | | | >360 | >1,000 | 3 | >100 | >1,000 |
| BR | | | | | | | |
| CC | | | | | | | |
| CP | | 2 | 5 | 25 | | | 5 |
| ES | | | | | | | |
| BB | | | | | | | |
| LT | | | | | | | |
| WS | | | | | 1 | | |
| SB | | | | | | | |
| SM | | 50 | | | 5 | | |
| LB | | | | | | | |
| BT | | | | | | | |
| LS | | | 4 | | | | |
| QB | | | | | | | |
| SR | | | | | | | |
| XC | | | | | | | |
| WL | | | | 1 | | | |
| Fish eggs[5] | | | | | | | |
| Riprap | | SS | AL,SP | AL | | | |
| Sand | | | | AL | | | |

(Continued).

Appendix 1. Continued.

| Category | Apr | May | Jun | Jul | Aug | Sep | Oct |
|---|---|---|---|---|---|---|---|
| | | | | 1979 | | | |
| No. of dives[1] | 3 | 3 | 3 | 3 | 3 | 2 | 2 |
| Periphyton[2] | | | | | | | |
| Structure | 0 | 0.5 | 1.5 | 3.0 | 6.0 | 1.0 | 1.0 |
| Riprap | 0.5 | 1.2 | 3.0 | 5.5 | 5.0 | 3.0 | 2.5 |
| Invertebrates[3] | | | | | | | |
| Crayfish | | 4 | | 8 | 1 | 6 | 5 |
| Snails | | | | | | | |
| *Hydra* | | | | | X | X | |
| Bryozoans | | | | | | | |
| Sponge | | | X | | X | X | |
| Other | | | | | | | |
| Fish[4] | | | | | | | |
| YP | | 99 | 1 | 170 | 36 | | 2 |
| JD | | 8 | 5 | 9 | 9 | | |
| SS | | 3 | 3 | 8 | 1 | | |
| TP | | 1 | | 2 | | 1 | 2 |
| SP | | 2 | | 36 | | 8 | 3 |
| AL | | | | 8 | >1,000 | 327 | >1,000 |
| BR | | 3 | | 1 | 1 | | |
| CC | | | | | | | |
| CP | | 8 | | 4 | 1 | 1* | |
| ES | | | | | | | |
| BB | | | | | | | |
| LT | | | | | | | |
| WS | | | | | | | |
| SB | | | | | | | |
| SM | | 5 | 3 | | | | |
| LB | | | | | | | |
| BT | | | | | | | |
| LS | | | 1 | | | | |
| QB | | | | | | 1 | |
| SR | | | | | | | |
| XC | | | | | | | |
| WL | | | | | | | |
| Fish eggs[5] | | | | | | | |
| Riprap | | YP | | AL | | | |
| Sand | | | | AL | | | |

(Continued).

Appendix 1. Continued.

| Category | Apr | May | Jun | Jul | Aug | Sep | Oct |
|---|---|---|---|---|---|---|---|
| | | | | 1980 | | | |
| No. of dives[1] | 2 | 2 | 3 | 3 | 2 | 2 | 3 |
| Periphyton[2] | | | | | | | |
| Structure | 0 | 0 | 2.0 | 1.6 | 6.5 | | 1.0 |
| Riprap | 3.0 | 1.8 | 1.5 | 6.0 | 1.0 | 1.3 | 1.0 |
| Invertebrates[3] | | | | | | | |
| Crayfish | 4 | 7 | | 13 | 10 | 5 | 5 |
| Snails | | | | | | | |
| *Hydra* | | X | | | | | |
| Bryozoans | | X | | | | | |
| Sponge | | | | | | X | |
| Other | | | | | | | |
| Fish[4] | | | | | | | |
| YP | | 15 | 114 | | 7 | 7 | |
| JD | | 2 | 10 | 3 | 3 | 31 | |
| SS | | 53 | 38 | | | 27 | |
| TP | 5 | 1 | | 1 | | | |
| SP | | | >106 | | | 7 | |
| AL | 79 | 1 | 15 | 40 | 50 | >103 | |
| BR | | 1 | 1 | | | | |
| CC | | | | | | | |
| CP | | | 30 | | | | |
| ES | | | | | | | |
| BB | | | 1 | | | | |
| LT | | | | 1 | | | |
| WS | | | | | 1 | | |
| SB | | | | | | | |
| SM | | 2 | 6 | 41 | 5 | 210 | |
| LB | | | | | | | |
| BT | 1 | | | | | | |
| LS | | | | | | | |
| QB | | | | | | | |
| SR | | | | | | | |
| XC | | | | | | | |
| WL | | | | | | | |
| Fish eggs[5] | | | | | | | |
| Riprap | | | AL | | | | |
| Sand | | | AL | | | | |

(Continued).

Appendix 1. Continued.

| Category | Apr | May | Jun | Jul | Aug | Sep | Oct |
|---|---|---|---|---|---|---|---|
| | | | | 1981 | | | |
| No. of dives[1] | 3 | 2 | 3 | 3 | 2 | 2 | 2 |
| Periphyton[2] | | | | | | | |
| Structure | 0 | 1.5 | 12.5 | 7.5 | 1.0 | 0.8 | 0.7 |
| Riprap | 1.0 | 2.5 | 5.0 | | 2.0 | 1.5 | 1.8 |
| Invertebrates[3] | | | | | | | |
| Crayfish | 4 | 9 | | 3 | | | 1 |
| Snails | | | | | | | |
| *Hydra* | | | | | | | |
| Bryozoans | | | | | X | X | |
| Sponge | | | | X | X | X | X |
| Other | | | | | P | P | |
| Fish[4] | | | | | | | |
| YP | | >110 | | 9 | >243 | | |
| JD | 2 | >109 | 28 | 5 | 4 | 1 | |
| SS | 21 | 89 | 11 | 1 | 3 | 22 | |
| TP | 1 | | >175 | 30 | 3 | 1 | |
| SP | 5 | 7 | 31 | 1 | 1 | | |
| AL | 4 | 60 | 15 | 40 | 2 | >1,000 | 4 |
| BR | | | | | | | |
| CC | | | | | | | |
| CP | 18 | | 30 | | | | |
| ES | | | | | | | |
| BB | | | | | | | |
| LT | | | | | | | 1 |
| WS | | | | | | 1 | |
| SB | | | | | | | |
| SM | | | 11 | 15 | | | |
| LB | | | | | | | |
| BT | | | | | | | |
| LS | | | | | | | |
| QB | | | | | | | |
| SR | | | | | | | |
| XC | | | | | | | |
| WL | | | | | | | |
| Fish eggs[5] | | | | | | | |
| Riprap | | YP | | | | | |
| Sand | | | | | | | |

(Continued).

Appendix 1. Continued.

| Category | Apr | May | Jun | Jul | Aug | Sep | Oct |
|---|---|---|---|---|---|---|---|
| | | | | 1982 | | | |
| No. of dives[1] | 1 | 2 | 2 | 3 | 3 | 2 | 2 |
| Periphyton[2] | | | | | | | |
| Structure | 0 | | | | | | |
| Riprap | 0.5 | 1.0 | | | 4.0 | | |
| Invertebrates[3] | | | | | | | |
| Crayfish | | | 3 | | | | 1 |
| Snails | | | | | | | |
| *Hydra* | | | | | X | | |
| Bryozoans | | | | | | | |
| Sponge | | | | | X | | |
| Other | | | | | | | |
| Fish[4] | | | | | | | |
| YP | | 12 | 44 | >765 | >131 | | |
| JD | | 5 | | | 7 | 1 | |
| SS | | 84 | 1 | 1 | 34 | 5 | 3 |
| TP | | | 1 | | | 2 | |
| SP | | | 2 | | 1 | 12 | |
| AL | | 1 | >178 | 1 | >170 | >114 | >1,000 |
| BR | | | | | 1 | | |
| CC | | | | 1 | | | |
| CP | | 3* | | >100 | >100+6* | | |
| ES | | | | | | | |
| BB | | | | | | | |
| LT | | | | | | | |
| WS | | | | 1 | | | |
| SB | | | | | | | |
| SM | | | | | | 3 | |
| LB | | | | | 1 | | |
| BT | | | | | | | |
| LS | | | | | | | |
| QB | | | | | | | |
| SR | | | | | | 1 | |
| XC | | | | | | | 1 |
| WL | | | | | | | |
| Fish eggs[5] | | | | | | | |
| Riprap | | | | | | | |
| Sand | | | | | | | |

1 Total number of standard series dives (usually three) made in the ripraped area surrounding the plant intake and discharge structures. From August 1977 to May 1982, diving in the area was reduced to only those occasions when water was not being discharged from one of the structures. During June 1982, the technical specifications for monitoring were reduced to two dives per month in the intake area only.

2 Length (cm) of periphyton on top of the structure and on riprap adjacent to the base of the structure as measured by divers.

3 Numbers of crayfish and snails were counted by divers. Values showing the greater than (>) symbol are totals which included open-ended estimates of 100+ or 1,000+ (see Fig. 2 and Methods). Presence of other invertebrates was noted (X) but animals were not enumerated. C = Chironomid (midge) larvae, E = Ephemeropterid (mayfly) larvae, M = *Mysis*, N = Notonectid (back swimmer), P = *Pontoporeia*, T = Trichoptera (caddisfly) larvae.

4 See Appendix 3 for scientific and common names, and abbreviations for fish. * = observed at intake stations.

5 Denotes observation of eggs of the fish species indicated during standard series dives on riprap substrate or during dives at reference stations north and south of the plant in areas of sand substrate.

Appendix 2. Duplicate observations made during transect swims in southeastern Lake Michigan, April through October, 1975-1982. Observations were made by two divers swimming side-by-side for 10 m along the base of the south intake structure of the D. C. Cook Nuclear Plant. Each diver examined an area 1 m wide. Total area of each transect was 10 $m^2$. Omitted swims are indicated by an asterisk (*). D = day, N = night.

| | Apr | | May | | Jun | | Jul | | Aug | | Sep | | Oct | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | D | N | D | N | D | N | D | N | D | N | D | N | D |
| | | | | | | | 1975 | | | | | | | |
| Invertebrates | | | | | | | | | | | | | | |
| Crayfish | * | * | 5,0 | * | 8,4 | 16,0 | 6,30 | 54,0 | 18,7 | 13,8 | 5,3 | 3,1 | 14,6 | 6,2 |
| Snails | * | * | 30,100 | * | 0,0 | 0,0 | 1,0 | 5,0 | 2,0 | 3,1 | 1,2 | 0,0 | 0,0 | 0,0 |
| Fish | | | | | | | | | | | | | | |
| Yellow perch | * | * | 4,0 | * | 30,0 | 0,0 | 2,1 | 0,0 | 8,7 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Alewife | * | * | 1,0 | * | 35,80 | 0,0 | 50,21 | 0,0 | 7,100,7,100 | 0,0 | 7,100,7,100 | 0,0 | 0,0 | 7,100,7,100 |
| Johnny darter | * | * | 4,0 | * | 0,0 | 0,0 | 15,3 | 23,0 | 9,4 | 2,4 | 0,0 | 4,0 | 0,0 | 0,0 |
| Sculpin | * | * | 50,100 | * | 6,0 | 15,0 | 5,17 | 16,0 | 7,4 | 2,0 | 3,2 | 3,0 | 4,8 | 1,3 |
| Spottail shiner | * | * | 0,0 | * | 50,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | | | | | | | 1976 | | | | | | | |
| Invertebrates | | | | | | | | | | | | | | |
| Crayfish | 3,0 | 0,0 | 10,6 | 0,0 | 11,4 | 2,0 | 40,23 | 3,6 | 32,4 | 15,8 | 50,22 | 1,0 | 2,3 | 0,0 |
| Snails | 0,0 | 0,0 | 1,0 | 1,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Fish | | | | | | | | | | | | | | |
| Yellow perch | 2,0 | 0,0 | 1,0 | 0,0 | 4,5 | 0,0 | 4,1 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 |
| Alewife | 0,0 | 0,0 | | 0,0 | 12,10 | 30,0 | 2,0 | 0,0 | >100,30 | 0,0 | 2,18 | 0,0 | 0,0 | 0,0 |
| Johnny darter | 0,0 | 0,0 | 2,0 | 4,6 | 8,4 | 4,3 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Sculpin | 3,1 | 1,0 | 17,8 | 2,5 | 16,17 | 2,3 | 5,6 | 1,0 | 14,1 | 1,4 | 1,6 | 1,0 | 2,4 | 0,0 |
| Spottail shiner | 0,0 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 |
| Rainbow smelt | 1,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Burbot | 0,0 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Trout-perch | 0,0 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |

(Continued).

Appendix 2. (Continued).

| | Apr N | Apr D | May N | May D | Jun N | Jun D | Jul N | Jul D | Aug N | Aug D | Sep N | Sep D | Oct N | Oct D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1977** | | | | | | | | | | | | | | |
| Invertebrates | | | | | | | | | | | | | | |
| Crayfish | 10,8 | 5,2 | 8,11 | 0,0 | 13,6 | 2,0 | 17,35 | 5,0 | 23,26 | 1,0 | 9,4 | 2,0 | * | * |
| Snails | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | 0,0 | * | * |
| Fish | | | | | | | | | | | | | | |
| Yellow perch | 0,0 | 0,0 | 2,6 | 1,0 | 1,1 | 2,1 | 6,3 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | * | * |
| Alewife | 0,0 | 0,0 | 0,0 | 1,0 | 15,8 | 50,25 | 1,0 | 0,0 | 1,1 | 0,0 | 1,0 | 0,0 | * | * |
| Johnny darter | 0,0 | 0,0 | 7,6 | 4,7 | 4,6 | 1,2 | 0,0 | 2,0 | 0,0 | 4,1 | 0,0 | 0,0 | * | * |
| Sculpin | 3,2 | 4,2 | 4,6 | 0,0 | 3,1 | 3,0 | 0,0 | 0,0 | 4,1 | 0,0 | 0,0 | 0,0 | * | * |
| Rainbow smelt | 2,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | * | * |
| **1978** | | | | | | | | | | | | | | |
| Invertebrates | | | | | | | | | | | | | | |
| Crayfish | * | * | 2,5 | 0,0 | 0,0 | 0,0 | * | 0,0 | 1,3 | 0,0 | 0,0 | 0,0 | * | 0,0 |
| Snails | * | * | 0,0 | 1,0 | 0,0 | 0,0 | * | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | * | 0,0 |
| Fish | | | | | | | | | | | | | | |
| Yellow perch | * | * | 1,0 | 0,0 | 2,8 | 8,0 | * | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | * | 0,0 |
| Alewife | * | * | 0,0 | 0,0 | 2,5 | 30,30 | * | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | * | >1,000,>1,000 |
| Johnny darter | * | * | 0,0 | 0,0 | 1,0 | 1,3 | * | 3,5 | 1,0 | 0,0 | 1,0 | 0,0 | * | 0,0 |
| Sculpin | * | * | 0,0 | 0,0 | 1,0 | 0,0 | * | 1,0 | 1,0 | 0,0 | 0,0 | 0,0 | * | 1,0 |
| Spottail shiner | * | * | 0,0 | 0,0 | 1,0 | 0,0 | * | 0,0 | 2,2 | 0,0 | 0,0 | 0,0 | * | 0,0 |
| Rainbow smelt | * | * | 2,1 | 0,0 | 0,0 | 0,0 | * | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | * | 0,0 |

(Continued).

Appendix 2. (Continued).

| | Apr | | May | | Jun | | Jul | | Aug | | Sep | | Oct | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | D | N | D | N | D | N | D | N | D | N | D | N | D |
| | | | | | | | 1979 | | | | | | | |
| Invertebrates | | | | | | | | | | | | | | |
| Crayfish | * | * | 3,1 | 0,0 | 0,0 | 0,0 | 8,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | 0,0 | 3,0 |
| Fish | | | | | | | | | | | | | | |
| Yellow perch | * | * | 6,6 | 0,0 | 0,0 | 0,0 | 5,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 |
| Alewife | * | * | 0,0 | 0,0 | 0,0 | 0,0 | 5,0 | 0,0 | 0,0 | >1,000,>1,000 | 2,0 | 0,0 | 5,0 | 0,0 |
| Johnny darter | * | * | 0,0 | 1,0 | 1,0 | 0,0 | 5,0 | 3,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Sculpin | * | * | 0,0 | 0,0 | 0,0 | 0,0 | 8,10 | 0,0 | 1,01 | 0,0 | 2,2 | 0,0 | 1,0 | 1,0 |
| Spottail shiner | * | * | 0,0 | 0,0 | 0,0 | 0,0 | 1,10 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Burbot | * | * | 2,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Trout-perch | * | * | 0,0 | 0,0 | 0,0 | 0,0 | 2,0 | 6,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | | | | | | | 1980 | | | | | | | |
| Invertebrates | | | | | | | | | | | | | | |
| Crayfish | 0,0 | 0,0 | 1,1 | 0,0 | 0,0 | 0,0 | 3,0 | 0,0 | 2,1 | 0,0 | 0,0 | 0,0 | 1,0 | 2,0 |
| Fish | | | | | | | | | | | | | | |
| Yellow perch | 0,0 | 0,0 | 2,0 | 0,0 | 2,0 | 0,0 | 0,0 | 0,0 | 2,5 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 |
| Alewife | 0,0 | 0,0 | 0,0 | 0,0 | 1,3 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Johnny darter | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 |
| Sculpin | 0,0 | 0,0 | 6,4 | 0,0 | 3,0 | 0,0 | 0,0 | 0,0 | 1,3 | 0,0 | 1,0 | 0,0 | 1,0 | 0,0 |
| Spottail shiner | 0,0 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 2,0 | 0,0 | 0,0 | 0,0 |
| Rainbow smelt | 0,0 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | 5,0 | 0,0 | 30,20 | 0,0 | 0,0 | 0,0 |
| Burbot | 0,0 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Trout-perch | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |

(Continued).

Appendix 2. (Concluded).

| | Apr | | May | | Jun | | Jul | | Aug | | Sep | | Oct | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | D | N | D | N | D | N | D | N | D | N | D | N | D |
| **1981** | | | | | | | | | | | | | | |
| Invertebrates | | | | | | | | | | | | | | |
| Crayfish | 4,0 | 1,0 | 4,0 | 0,0 | 0,0 | 0,0 | 1,1 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Fish | | | | | | | | | | | | | | |
| Yellow perch | 0,0 | 0,0 | 8,0 | 0,0 | 2,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Alewife | 4,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 2,0 | 0,0 | 2,0 | 0,0 | 0,0 | 0,0 |
| Johnny darter | 2,0 | 0,0 | 0,0 | 3,1 | 2,0 | 4,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Sculpin | 20,0 | 0,0 | 2,0 | 2,0 | 3,3 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Spottail shiner | 5,0 | 0,0 | 5,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 2,1 | 0,0 | 0,0 | 0,0 |
| Rainbow smelt | 0,0 | 0,0 | 0,0 | 0,0 | 6,5 | 0,0 | 5,10 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Trout-perch | 1,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| **1982** | | | | | | | | | | | | | | |
| Fish | | | | | | | | | | | | | | |
| Yellow perch | 0,0 | 0,0 | 2,0 | 5,0 | 1,12 | 0,0 | * | * | * | * | * | * | * | * |
| Alewife | 0,0 | 0,0 | 0,0 | 0,0 | 2,5 | 30,30 | * | * | * | * | * | * | * | * |
| Sculpin | 0,0 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | * | * | * | * | * | * | * | * |
| Spottail shiner | 0,0 | 0,0 | 0,0 | 0,0 | 1,0 | 0,0 | * | * | * | * | * | * | * | * |

Appendix 3. Scientific name, common name, and abbreviations for species of fish observed by divers in southeastern Lake Michigan near the D. C. Cook Nuclear Plant, 1973-1982. Names were assigned according to Robins et al. (1980).

| Scientific name | Common name | Abbreviation |
|---|---|---|
| Alosa pseudoharengus (Wilson) | alewife | AL |
| Carpiodes cyprinus (Lesueur) | quillback | QL |
| Catostomus catostomus (Forster) | longnose sucker | LS |
| Catostomus commersoni (Lacepede) | white sucker | WS |
| Coregonus spp.[1] | unident. coregonid | XC |
| Cottus spp.[2] | unident. cottid | SS |
| Cyprinus carpio Linnaeus | common carp | CP |
| Etheostoma nigrum Rafinesque | johnny darter | JD |
| Ictalurus melas (Rafinesque) | black bullhead | BB |
| Ictalurus punctatus (Rafinesque) | channel catfish | CC |
| Lota lota (Linnaeus) | burbot | BR |
| Micropterus dolomieui Lacepede | smallmouth bass | SB |
| Micropterus salmoides (Lacepede) | largemouth bass | LB |
| Moxostoma macrolepidotum (Lesueur) | shorthead redhorse | SR |
| Notropis atherinoides Rafinesque | emerald shiner | ES |
| Notropis hudsonius (Clinton) | spottail shiner | SP |
| Osmerus mordax (Mitchill) | rainbow smelt | SM |
| Perca flavescens (Mitchill) | yellow perch | YP |
| Percopsis omiscomaycus (Walbaum) | trout-perch | TP |
| Salmo trutta Linnaeus | brown trout | BT |
| Salvelinus namaycush (Walbaum) | lake trout | LT |
| Stizostedion vitreum vitreum (Mitchill) | walleye | WL |

1 May include both Coregonus artedii Lesueur (lake herring or cisco) and Coregonus hoyi (Gill) (bloater) because divers could not distinguish between these species while underwater.

2 May include both Cottus cognatus Richardson (slimy sculpin) and Cottus bairdi Girard (mottled sculpin) because divers could not distinguish between these species while underwater.